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The Effects of Training on Visual-spatial Disembedding Skills in Early Childhood

Author
Avant, Sherice Brake

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The Effects of Training on Visual-spatial Disembedding Skills in Early Childhood

This dissertation is submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in the Department of Education.

by

Sherice Brake Avant

Committee:

Professor Laura Romo, Co-Chair

Professor Yukari Okamoto, Co-Chair

Professor Danielle Harlow

June 2017

The Dissertation of Sherice Brake Avant is approved.

Danielle Harlow

Yukari Okamoto, Committee Co-Chair

Laura Romo, Committee Co-Chair

March 2017

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DEDICATION

For
William Garrett Avant
&
Christopher James Brake

VITA OF SHERICE BRAKE AVANT
March 2017

EDUCATION

University of California, Santa Barbara
Ph.D. Education, Child and Adolescent Development (March 2017)
Gevirtz Graduate School of Education,
Committee Members: Drs. Laura Romo, Yukari Okamoto, Danielle Harlow

M.A. Education, 2015
Thesis Title: Children's spatial and geometric thinking in an embodied shape-search task: The role of outdoor versus indoor preschool settings

California State University, Sacramento
B.A. Child Development, 2013

TEACHING EXPERIENCE

Teaching Assistant (Fall, 2014)
University of California, Santa Barbra, Gevirtz Graduate School of Education, Department of Education.
Education 111 – Introduction to Child & Adolescent Development
- Prepared for and led weekly discussion sections.
- Lectured on various aspects of child and adolescent development including physical, cognitive, and social developmental.
- Proctored examinations and recorded grades.

RESEARCH EXPERIENCE

Graduate Student Research Assistant (Winter 2014 – Fall 2016)
University of California, Santa Barbara, Chicano Studies Institute
Project Investigators: Drs. Laura Romo, Yukari Okamoto, Julie Bianchini
- Implemented a health and biology curriculum designed to foster a conceptual understanding of germ contagion and contamination, as well as of food and nutrition amongst low-income Latino preschoolers.

Graduate Student Research Assistant (Summer 2014)
University of California, Santa Barbara, Gevirtz Graduate School of Education, Department of Education
Project Investigators: David Hallowell, Dr. Yukari Okamoto, Dr. Laura Romo, Jonna La Joy
- Assisted in coding children's performance on a shape-sorting task for a study on first-grade children's understanding of plane and solid shapes.

RELATED PROFESSIONAL EMPLOYMENT

Toddler Teacher & Administrative Assistant (September 2013 – December 2014)
Hope 4 Kids Preschool, Santa Barbara, CA

- Managed front office operations; helped organize and implement small school events.
- Created a school-wide template to document children's' development.
- Cared for infants and toddlers in compliance with all applicable local, state, and federal regulations.

Pre-Kindergarten Teacher (September 2011 – August 2013)
La Petite Academy, Sacramento, CA

- Created and led instructional activities focused on physical, cognitive, and social development.
- Monitored and recorded students progress and achievements and identified areas in need of further development.

PROFESSIONAL AFFILIATIONS

National Association for the Education of Young Children
Society for Research in Child Development
American Education Research Association

ABSTRACT

The Effects of Training on Visual-spatial Disembedding Skills in Early Childhood

by

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The overall goal of the present study was to develop, implement, and test the effectiveness of a curriculum designed to improve spatial thinking amongst preschool children. Specifically, the study explored the effects of shape-based training on 4-year-old children's ability to disembed and whether the training transferred to improvement in mental rotation skills.

Participants were recruited from preschools in the Central California Coast region. The treatment group included 20 children, 9 boys and 11 girls ($M = 4.48$, $SD = .27$) and the control group included 20 children as well, 10 boys and 10 girls ($M = 4.50$, $SD = .27$). Children in the control condition received a basic shape curriculum that focused on teaching children about shape attributes. Children in the treatment condition received the basic shape curriculum as well but also participated in activities that encouraged the development of disembedding skills.

Findings from this study suggest that minimal training can improve preschool children's spatial abilities. Children in both conditions showed improvement on an embedded figures test and two newly developed spatial measures but there were no intervention group effects. That is, both the intervention and control group children improved in their ability to recognize shapes and disembed shapes. However, the improvements did not transfer to a mental rotation task. Correlations provide evidence to support the newly created measures as methods of assessing preschool children's ability to disembed hidden figures and mentally rotate objects. The significance of the findings as well as implications for future research are discussed.

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Chapter I

Introduction

Children enter preschool with intuitive spatial knowledge gained from their daily experiences in the world - inserting shapes into shape sorters, categorizing them, and building blocks, to name a few. In doing so, children learn to describe objects in the environment and the relationships between objects and the space around them. These experiences contribute to the development of spatial thinking (i.e., the ability to perform mental operations such as locating, decomposing, transforming, and rotating objects).

Several studies have shown that various types of play are associated with greater competencies in spatial reasoning. Coates, Lord, and Jakabovics (1975) found that preschool children who participated in activities such as puzzles, painting, and block play performed better on standard tasks that measured their ability to locate shapes amid complex backgrounds. As another example, Levine, Ratliff, Huttenlocher, and Cannon (2012) found that children who engaged in puzzle play performed better on a spatial transformation task, which required that children mentally rotate one stimulus to align it with a comparison stimulus. The more children participated in puzzle play, the better their performance was on the task. Such findings indicate that children should be given ample opportunity to engage in these types of activities.

Identifying activities that improve children's spatial thinking is important because such skills facilitate success in mathematics (e.g., Verdine, Golinkoff, Pasek, Newcombe, Filipowicz, & Chang, 2014; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014; Wolfgang, Stannard, & Jones, 2003), both concurrently and predictively. For example, Gunderson, Ramirez, Beilock, and Levine (2012) found that children's spatial skills at age 5, as measured by a mental rotation task, predicted their number line knowledge at age 6, which in turn predicted their performance on adding and subtracting symbolic quantities at age 8. Spatial skills at early ages seem to also predict math performance in high school. In a longitudinal study, Wolfgang, Stannard, and Jones (2003) observed 3- and 4-year old preschool children playing with LEGO blocks and rated their play in terms of their level of attention to physical or representational properties. Children who played with blocks in a highly insightful manner at preschool age achieved higher grades in algebra, geometry, and statistics in high school years later. These findings suggest that playing with blocks provides a foundation for later mathematics proficiency.

Outcomes such as these have spurred interest in the question of whether spatial skills are trainable in early childhood (Casey, Andrews, Schindler, Kersh, Samper, & Copley, 2008; Taylor & Hutton, 2013; Cheng & Mix, 2014). Tzuriel and Egozi (2010) implemented an intervention program to explore the effects of training on first-grade children's spatial visualization skills. During each session, the children were shown a projected figure and then asked to draw the figure from memory. After the children attempted to draw the figure from memory, a researcher encouraged the children to examine the image a second time, this time rotating it and looking at it from a different perspective. The control group was shown the same images but did not receive group discussion or guidance to reexamine the figures. It was found that children who participated in the intervention condition significantly improved their scores on a mental rotation task. Cheng and Mix (2014) reported similar results on a one-time 40-minute mental rotation-training lesson for 6- to 8-year-old children. The training allowed the children to physically manipulate the pieces to gain a deeper understanding of how they must be rotated to fit together. The results revealed that children who received the training did better on a math test and mental rotation task after the lesson. These findings indicate that even minimal training can be useful in strengthening children's performance on mental rotation tasks.

The overall goal of the present study was to test the efficacy of a classroom curriculum developed to improve preschool children's disembedding skills. Disembedding is considered an intrinsic-static spatial skill that requires the viewer to mentally piece apart a visual scene in order to focus on important information. At present, the literature on the development of spatial skills is weighed heavily toward mental rotation skills (intrinsic-dynamic) and considerably less research has focused on other components of spatial thinking. Although intrinsic-static reasoning has been linked to the visual arts (Kozhevnikov, Kosslyn, & Shephard, 2005), research suggests that the ability to disembed is also associated with mathematics achievement. For example, among a sample of children in 2nd through 7th grades, Guay and McDaniel (1977) utilized scores on the Iowa Tests of Basic Skills to classify children as high or low mathematics achievers. The children were also tested on four spatial tasks that measured their performance on low- and high-level spatial abilities that included disembedding figures. The researchers found that children who exhibited higher mathematical abilities performed better on all of the spatial tasks than did children with lower mathematical abilities. Similarly, Roberge and Flexer (1983) examined the relationship between the ability to disembed and mathematics achievement amongst 6th, 7th, and 8th grade students. The students were given the Group Embedded Figures Test (Oltman, Raskin, & Witkin, 1971) and a mathematics achievement test. The results revealed that, at all three grade levels, students who exceled on the embedded figures task scored significantly higher on the mathematics achievement test compared to students who performed poorly on the embedded figures task. These findings support the practical importance of enhancing children's disembedding skills at young ages.

Disembedding involves identifying figures that are located within a larger configuration of shapes. As such, shape instruction is a practical venue for teaching this spatial skill. When geometry content is taught in preschool classrooms, the stress is on shape naming and shape attributes rather than on spatial reasoning (Clements, 2004). Training children to distinguish embedded figures while learning about shape attributes is a natural extension of shape education.

A limitation in testing the effectiveness of the intervention is the lack of age-appropriate disembedding measures. Therefore, two new disembedding measures were designed for the purpose of this study that capitalized on children's interest in solving puzzles and playing visual search games such as *"I Spy"* (locating a hidden object in a complex scene). The pretest afforded an opportunity to examine the construct validity of these newly created measure by examining how their scores correlated with a standard disembedding measure commonly used in studies with young children. Because the newly created measures were dynamic in nature, in that they required eye movements to scan a visual drawing and mentally rotate a puzzle piece, children's performance on these measures were compared to scores on a standard children's mental rotation measure. Correlational analyses helped to determine whether the newly created measures had elements in common with the standard measures.

In the next chapter, I review the literature motivating this study. The first section describes the classification of spatial reasoning skills and the developmental progression of children's ability to disembed. The relationship between the spatial skill of disembedding and mathematics achievement is discussed next. In addition, I summarize the limited literature on training programs aimed at improving spatial abilities and the transferability of spatial skills during childhood. In the final section, I discuss demographic differences in early spatial development. Chapter two concludes with a description of the rationale for the intervention, the purpose of the study, and the relevant research questions. In Chapter 3, I present the methods that were utilized to implement the study and a description of the concepts that were taught in the treatment and the control groups. Chapter 4 presents results from the analyses. Finally, Chapter 5 provides a summary of the study and findings, interpretations of the results, an overview of the limitations, and recommendations for future research.

Chapter II

Literature Review

Classification of spatial reasoning skills

There are multiple skills under the broad umbrella of spatial reasoning, and only recently has the field found a way to describe how these skills align with one another. Newcombe and Shipley (2015) developed a typology that defines spatial skills in two dimensions: intrinsic versus extrinsic and static versus dynamic. Spatial activities that involve defining an object or identifying the distinguishable characteristics of a single object are classified as intrinsic. It is an intrinsic process because the task requires only thinking of the object at hand, without consideration of the object's surroundings. Extrinsic representations refer to the spatial relations between objects. Take, for example, a child looking at a house on a piece of paper that has a square to represent the base and a triangle to represent the roof. Intrinsic information allows the child to distinguish the differences between the triangle and square while extrinsic information allows the child to recognize that the triangle is on top of the square. Static and dynamic information refers to the immobility or movement of objects. An object can remain static to the participants, not changing in orientation, location, or dimension. In contrast, dynamic information examines the manipulation of an object, either physically or mentally. For example, using the previous example, the house can be viewed as a stationary object (static) or as a 3D object that can be rotated or moved (dynamic).

When these dimensions are combined, four categories emerge to create a 2x2 framework: intrinsic-static, intrinsic-dynamic, extrinsic-static, and extrinsic-dynamic. Uttal et al. (2013) have identified corresponding skills within each of the four categories (building on a classification scheme proposed by Linn and Petersen, 1985). These are: disembedding, i.e., distinguishing overlapping or embedded images (intrinsic-static skills); spatial visualization and mental rotation, which involves rotating, folding, or scaling of an object (intrinsic-dynamic skills); spatial perception, which includes comparing and making inferences about spatial relations between different objects (extrinsic-static skills); and perspective taking, which includes examining objects through changes in perspective (extrinsic-dynamic skills). This framework facilitates a systematic approach to researching the malleability of each category of spatial skills.

Developmental progression of children's disembedding skills

Studies on early spatial development have shown that spatial reasoning skills begin developing as early as infancy (Frick & Wang, 2014) and continue to develop through childhood and adolescence (Witkin, Goodenough, Karp, 1967). Clements and Sarama (2014) recently proposed that the ability to disembed is characterized by different stages. A child at 4 years of age is considered a "*simple disembedder*" in that he/she "Identifies frames of complex figures. Finds some shapes in arrangements in which figures overlap, but not in those in which figures are embedded within others" (p. 183). For example (see Figure 1 below), if children are presented with figure A, they are able to discern figure B when asked to locate a shape within figure A.

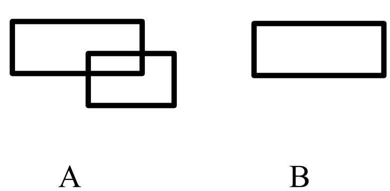
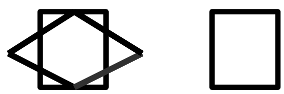


Figure 1. Example problem for "*simple disembedder*" stage.

A child at 5 or 6 years of age is a “*shapes-in-shapes disembedder*.” According to Clements and colleague, a child at this age “identifies shapes embedded within other shapes” (p. 184) (see Figure 2 below). Or, a child can identify a primary structure within a complex figure (see Figure 3).

A B

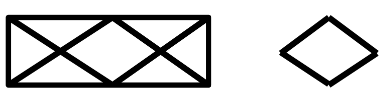
Figure 2. Example problem for “*shapes-in-shapes disembedder*” stage.



A B

Figure 3. Example problem for “*shapes-in-shapes disembedder*” stage.

A child at 7 years of age is a “*secondary structure disembedder*.” He/she “identifies embedded figures even when they do not coincide with any primary structure of the complex figure” (p. 184) (see Figure 4 below). These trends describe a tentative learning trajectory that could be useful in designing age-appropriate materials to help develop children’s disembedding skills.



A B

Figure 4. Example problem for “*secondary structure disembedder*” stage.

Although the proposed stages of disembedding by Clements and Sarama (2014) provides a general outline for what children might be capable of at different ages, there is little empirical research supporting this trend.

A handful of studies suggest that there are age-related differences in young children's ability to disembed hidden figures. One of the first studies that examined age-related performance on disembedding tasks was conducted by Ghent (1956). The sample consisted of 90 children ages 4 to 12 years. The task utilized overlapping outlines of familiar objects. The children were asked to name everything in the pictures or to trace it with their finger. For example, children were shown a drawn picture consisting of overlapping outlines of a banana, pear, orange, apple, and grapes and asked to identify all of the items they could see (see Figure 5). The children were also encouraged to turn the picture to examine the outlines from different angles. Scores were calculated based on how many items the children failed to identify in each picture. Not surprisingly, Ghent (1956) found that older children (6-to 12-year-olds) made fewer omissions compared to younger children (4- to 5-year-olds). In addition, in the 6 to 12-year-old age range, roughly 50 to 85% of the children made no omissions. However, only 13% of the 4- to 5-year-old age group made no omissions, indicating that the younger children had difficulty piecing apart the drawn objects.

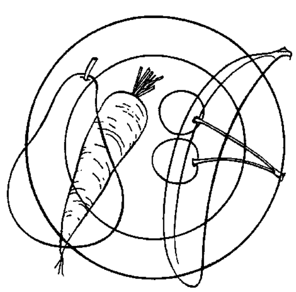


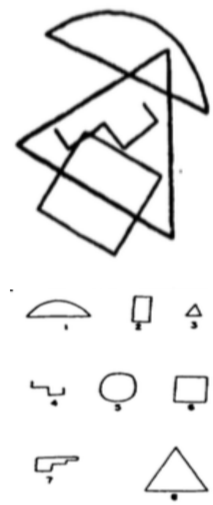
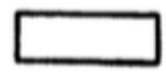
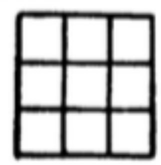
Figure 5. Example problem utilizing overlapping outlines of familiar objects.

Ghent (1956) questioned whether the study task truly assessed children's ability to disembed shapes because of its sole focus on distinguishing shapes from overlapping outlines. Thus, a second study was conducted utilizing a task that required children to disembed shapes within geometric figures in addition to distinguishing overlapping outlines of familiar objects. Thirty-four 4- to 8-year-old children were shown three different sets of pictures. The first and second set of pictures consisted of overlapping outlines of either realistic items or geometric figures. The third set consisted of geometric figures embedded within a drawing. Table 1 provides example test items from the three types of tasks.

In the overlapping outlines of realistic figures, children were asked to name everything in the pictures or to trace it with their finger. In the overlapping outlines of geometric figures, children were presented with a sheet that had drawings of shapes on it and were asked to trace all of the shapes they could find in the image. For the geometric figures task, the children were shown a simple figure and asked to locate it within a more complex figure, for example, disembedding a rectangle from a group of connected squares. For the overlapping outlines test, scores were calculated based on how many items the children failed to identify when shown each picture. Errors on the embedded figures test were calculated when a child inaccurately traced the target figure in the more complex figure.

Table 1

Sample Test Items From The Three Types Of Tasks Utilized In Ghent (1956).

Overlapping Outlines (Realistic Figures)	Overlapping Outlines (Geometric Figures)	Embedded Geometric Figures
		Simple Shape   Complex figure

Overall, the results revealed that all of the children made significantly fewer errors on the first and second sets of diagrams with overlapping outlines than they did on the embedded geometric figures test. Four- and five-year-olds made two to four omissions on the embedded figures test while 6- to 8-year-olds made one to three omissions. Ghent (1956) proposed that young children's poorer performance on the embedded figures task was due to difficulty in distinguishing figures that share contours. The shapes in the overlapping outlines sets retained predefined boundaries and although there may have been areas that were more difficult to distinguish, the outlines maintained a complete shape. However, the embedded figures set required that children piece apart a figure that did not have clear and separate boundaries.

Clements, Swaminathan, Zeitler Hannibal, and Sarama (1999) obtained similar findings while assessing 97 three to six-year-old children's ability to disembed shapes on an overlapping and embedded figures task. The task consisted of printed outlines of overlapping squares and circles with some shapes embedded within other shapes (e.g., a square within a circle). Figure 6 depicts the diagram utilized their study.

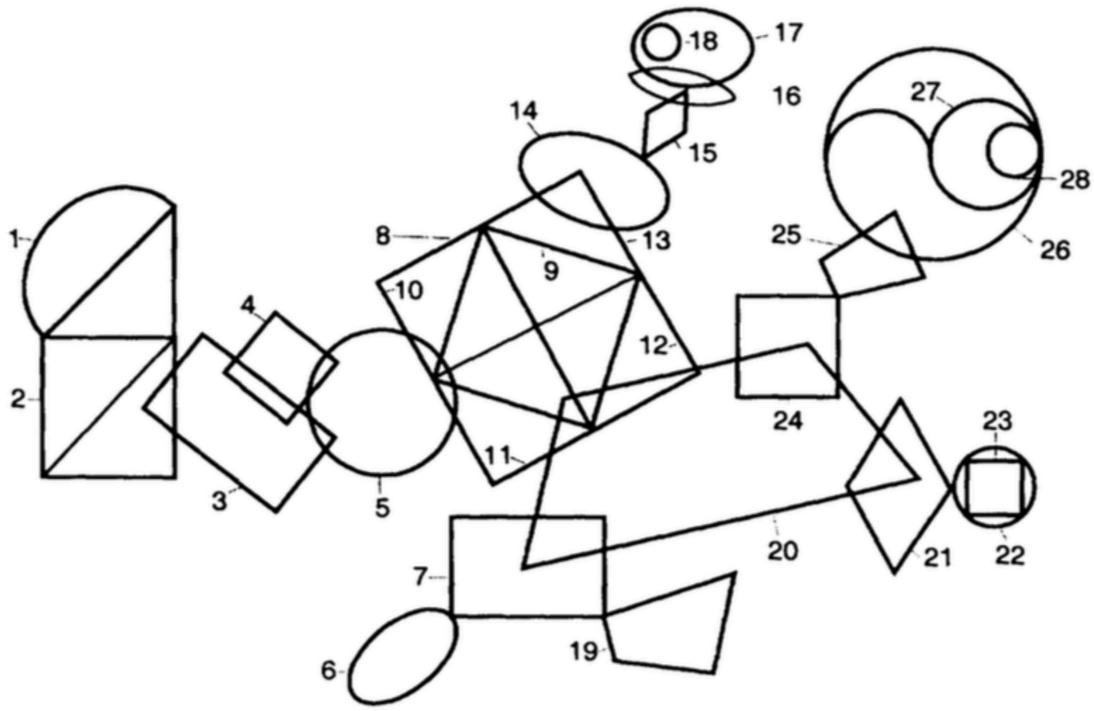


Figure 6. Overlapping and embedded figures task from Clements et al. (1999).

The children were asked to mark all of the examples of squares and circles using a pen. Overall, the 6-year-old children identified significantly more shapes on this task than their younger counterparts. Also, children were more likely to identify overlapping circles and squares than embedded circles and squares. For example, about half of the younger children identified shape 14 as a type of circle and the overall outline of shape 8 as a square (despite the fact that it was rotated). The ellipse that partially overlaps the square is distinguishable because both shapes have separate outlines. In contrast, only 17% identified the upright embedded square (shape 9) and even fewer children identified squares in the quadrants (shapes 10 - 13). Therefore, discerning 2D shapes that are embedded within other shapes is more difficult for young children than discerning shapes in drawings of objects that have overlapping outlines.

One task that has been commonly utilized to measure young children's ability to disembed shapes is the Preschool Embedded Figures Test (PEFT) (Coates, 1972). The PEFT requires 3- to 5-year-old children to identify a triangle or house-shape embedded within a familiar item such as a stroller or tent (Figure 7). Coates (1974) utilized this task to explore age related differences among a sample of 3- to 6-year-old preschool children in their ability to disembed figures. The results revealed that the 6-year-old age group performed significantly better on the task than the younger children, indicating that children's disembedding skills improve significantly after the age of five.

Figure 7. Example image from CEFT.

Bigelow (1971) offers additional support for the notion that older children have more sophisticated disembedding skills than younger children. The researcher assessed children's performance on the Children's Embedded Figures Test (CEFT) (Karp and Konstadt, 1971), a measure that is very similar to the PEFT. The CEFT was developed for children between the ages of 5 and 9 years. The sample included children from the ages of 5 to 10 years. The children were split into groups of 5- to 6-year olds, 6- to 7.5-year-olds, 7.5- to 8.5-year-olds, and 8.5- to 10-year-olds. The results revealed that children in the two younger age groups (5- to 6- year-olds, 6- to 7.5-year-olds) scored significantly lower than the children in the two older age groups (7.5- to 8.5-year-olds, and 8.5- to 10-year-olds). Bigelow (1971) suggests that children around the age of 8 are better able to perceive parts of a drawn object while younger children view the image primarily as a whole.

A later study examined the types of strategies that children use to locate hidden figures and how strategies differ by age. Pennings (1988) administered the Diagnostic Embedded Figures Test (Aalders & Pennings, 1981) to a sample of children ages 5 to 7 years. The Diagnostic Embedded Figures Test was utilized because it allows for the use of different strategies when locating hidden figures. Children were shown a simple figure and a complex pattern in which the simple figure was hidden. They were provided with four different ways to solve the problem, ordered from most complex to least complex. The experimenter recorded which type of strategy enabled the child to successfully detect the hidden object. Specifically, each problem began by prompting the child to use the simultaneous strategy, in which the child was required to memorize the simple figure and then find it in the complex pattern. If the child was not able to locate the figure from memory, the child was given the opportunity to use the successive strategy. The successive strategy required that the child keep in mind the lines of the simple figure and mentally match them to corresponding lines in the complex pattern. If the child could not locate the figure using the successive strategy, the externalized-successive strategy was prompted. In the externalized-successive strategy, the child carries out the successive strategy utilizing hands-on materials to enhance the child's ability to locate the hidden shape. Finally, if the child could not solve the problem using the externalized successive strategy, she was prompted to use the global-manipulatory strategy. This hands-on strategy involved the child using a transparent cutout of the simple figure to move around the complex pattern until she matches the transparent cutout with the simple figure. Both the simultaneous strategy and the successive strategy are carried out on a mental level and are considered to be more complex than the externalized-successive strategy and the global manipulative strategy.

Pennings (1988) found that children at the age of 5 years relied more on the global-manipulative strategy while children ages 6 and 7 years relied more on the externalized-successive and successive strategies. This indicates that children may progress from hands-on strategies that are less complex to mental problem-solving strategies that are more complex when detecting hidden objects. This study further supports the notion that the ability to disembed experiences developmental changes around the age of six.

Together, these studies suggest that children's ability to disembed shapes exhibits significant developmental changes from the ages of three to ten. At age three and four, children demonstrate an inability to consistently locate hidden figures. By age five and six, children exhibit some ability to disembed shapes but still present difficulties on the majority of current tasks. It is not until around the age of seven that children exhibit more advanced disembedding abilities. Presently, there is only a small body of research examining preschool children's performance on the embedded figures test as related to their spatial abilities and shape understanding. Thus, the present study addressed the general question of whether the disembedding skills of 4-year-old children could be improved through a curriculum that trained children to disembed shapes while learning about shape properties.

Academic achievement and the ability to perceive embedded figures

Few studies have examined the relationship between mathematics achievement and the spatial skill of disembedding. In one study, Guay and McDaniel (1977) investigated the relationship between spatial ability and mathematics achievement amongst children in elementary school. The sample consisted of 90 children in 2^{nd} through 7^{th} grade. Children's scores on the Iowa Tests of Basic Skills were utilized as a measurement of their mathematics achievement. Children were classified as either high mathematics achievers or low mathematics achievers, depending on their scores. The children were also tested on four spatial tasks that measured their performance on low- and high-level spatial abilities. Low-level spatial tasks were considered tasks that only required the child to visualize two-dimensional configurations. The first low-level ability task required the children to view single lines projected one at a time and determine which shape would be made if the lines were combined. The second low-level ability task required the children to view a simple two-dimensional figure and then determine which of four complex designs the simple figure was embedded in. It is important to note that only children in fifth, sixth, and seventh grade were administered this task. High-level spatial tasks were considered tasks that required the children to visualize and mentally manipulate three-dimensional configurations. The first high-level ability task required the children to imagine what an object would look like from a different perspective and then choose which of three images represented the indicated viewpoint. The second high-level ability task required the children to visualize what a three-dimensional object would look like unfolded and then choose which of three drawings represented the unfolded object.

Guay and McDaniel (1977) reported a positive relationship between children's spatial abilities and their mathematics achievement. Specifically, they found that children who exhibited higher mathematical abilities performed better on all of the spatial tasks than children with lower mathematical abilities. There was also a significant effect of grade, indicating that children performed better on the spatial tasks as they got older. Further, the results revealed that the relation between spatial ability and mathematics achievement existed for both low and high-level spatial abilities. This means that children who performed better on the mathematics achievement test also performed better on all of the spatial tasks, regardless of if the task was considered a high- or low-level ability spatial task. Thus, the embedded figures task, although considered a low-level ability task, is related to mathematics achievement amongst elementary school children.

Tinajero and Paramo (1997) also found a relationship between students' ability to disembed and their academic achievement. The sample included 408 high school students between the ages of 13 and 16 years. The students were given three tests to measure their field independence. Field independence refers to a model of cognitive learning styles that attempts to explain the methods in which people gain information. Individuals who are considered field independent are better at separating details from a larger context while individuals who are field dependent consider the context as a whole instead of piecing it apart. The three tests included the Embedded Figures Test (Witkin, 1971), the Group Embedded Figures Test, and the Rod and Frame Test. Intelligence was assessed using the

Culture Fair Intelligence Test (Cattell & Cattell, 1986) that provides non-verbal visual puzzles in an attempt to measure cognitive abilities devoid of language and cultural biases. Academic achievement was calculated using students' average grades from a variety of classes (e.g., foreign language, mathematics, natural sciences, and social sciences). The results revealed that overall, field-independent students achieved higher grades than field dependent students. Namely, students who excelled at disembedding performed better academically. Further, the observed positive relationship between the ability to disembed and academic achievement was the same for both boys and girls.

In a more recent study, Nicolaou and Xistouri (2011) explored the relationship between 6th grade children's disembedding skills and problem posing abilities. The sample included 94 students who were 11 to 12 years of age. The students were given the Group Embedded Figures Test (Oltman, Raskin, & Witkin, 1971) to assess their ability to disembed hidden figures. Students were categorized as field independent, field dependent, or field mixed based on their scores from this task. Field mixed referred to students who scored in-between field independent and field dependent students. The students were also given a test that assessed their ability to construct "problem posing" mathematical problems. Problem posing refers to mathematical questions produced as a means to solving a problem. For example, the students were shown an image of a person sitting in front of a birthday cake with candles that read "50" and four balloons in the background. The students were then asked to construct two mathematical problems in relation to the image. Students were scored based on the complexity of the mathematical problem they constructed. For example, basic problems including addition or subtraction received a score of 1 and complex problems including proportions or fractions received a score of 2. The complexity scores were summed to create an overall score.

The results revealed that field independent students performed significantly better on the problem posing tasks than the field dependent or field mixed students. This indicates that students who are better at detecting hidden figures are also better at constructing mathematical problems. In addition, field independent students constructed more complex problems than the other two groups. Field independent students also did better on tasks that involved visual representations of the math problem. Overall, it appears that students who are better able to reorganize and focus on specific pieces of the problem perform better on certain mathematical tasks. This may be because disembedding requires analytical thinking as opposed to a holistic approach to thinking.

The general conclusion from these studies is that students who excel at disembedding figures or who are considered field independent outperform those who are considered field dependent on a variety of tasks that assess mathematical achievement. This indicates a relationship between disembedding and academic achievement beginning in early elementary school and continuing through high school. Together, these findings support the practicality of enhancing children's disembedding skills at young ages.

Can training improve children's spatial skills?

Because the development of spatial skills is linked to various types of experiences, researchers propose that spatial skills can be trained or taught. For example, playing dynamic puzzle games like *Tetris* can improve older children's and young adults' ability to rotate objects mentally (e.g., Cherney, 2008; De Lisi & Wolford, 2002; Okagaki & Frensch, 1994; Terlecki, Newcombe, & Little, 2008). A relatively smaller percentage of training studies have focused on developing young children's spatial abilities, despite the fact early childhood is an ideal time to develop these skills (Uttal et al., 2013). This is particularly true for disembedding.

In one study, Connor, Serbin, and Schackman (1977) implemented a brief visuospatial training lesson designed to facilitate performance of children in 1st, 3rd, and 5th grades on the CEFT. There were 133 children ranging from the ages of 6 to 10 included in the study. There were two training conditions and one control condition. The first condition was considered the "overlay" training condition. In the overlay condition, children were asked to locate a diamond within complex pictures. The complex pictures were drawn onto transparent overlays that guided the children through the process of discerning the embedded diamond. Specifically, as each transparent overlay was removed, part of the background detail in the picture was removed and the salience of the diamond was enhanced. When the last overlay was removed, only the diamond remained. The overlays were then put back over the diamond in three successive steps so that the children could see the shape become embedded in detail. The second condition was considered the "flat figures" training condition. In the flat figures condition, the children were shown the same complex pictures with the embedded diamond but the pictures were simply printed on paper and did not include transparent overlays. The diamond was pointed out if the children could not locate it. The control group did not receive any training.

The researchers found effects of training but only for girls. Among the girls, children in the overlay group scored significantly higher on the CEFT than did children in the flat figures group and the control group. For the boys, the scores of the overlay, flat figures, and control groups did not differ. One proposed interpretation for the gender differences offered by the researchers was that the disembedding skills of the boys was developed to high capacity prior to entering the experimental situation because boys typically spend more time playing with blocks and trucks. The girls, on the other hand, may have had less developed disembedding skills prior to the intervention. The fact that the boys in the control group performed better than the girls did on the CEFT partially supports Connor and colleague's interpretation. Overall, the results from this study suggest that a brief visuospatial training lesson has the potential to improve the disembedding skills of children who have limited spatial skills.

Pennings (1991) also conducted an intervention study that investigated whether children's strategy use in disembedding could be improved. Forty-eight children were included in the study, ranging from 7 to 8 years of age. The children were randomly assigned to one of two training groups or a control group. The two training groups were termed the "restructuring in perception program" and the "conservation of horizontality program." The "restructuring in perception program" focused on teaching children about shapes and embedded figures. In a four- unit curriculum, the children explored shapes through physical and visual aids, practiced drawing shapes from memory, learned how to draw shapes line-by-line, and filled in the outline of familiar images with shapes. In the final unit, children were shown partial drawings of objects and asked to interpret what the drawing was within five seconds. The children in the "conservation of horizontality program" were exposed to four units that taught them how to solve Piaget's Water-Level Task. In this program, the children learned about the concepts of orientation and measurement, developed an understanding that water lines are horizontal, and examined correct and incorrect drawings of water lines. For each of the training groups, the students were exposed to 12 sessions in six weeks, with each lesson lasting approximately 30 minutes. A control group of children received no training.

The pre- and posttest measures included the Diagnostic Embedded Figures Test, which scored children's ability to locate hidden figures. The children were prompted to use different strategies to solve the problem ordered from most complex to least complex (described in Pennings, 1988). Children received a score of 4-points if they detected the hidden figure correctly on the first attempt (simultaneous strategy), 3-points on the second try (successive strategy), 2-points on the third attempt (external successive strategy), and 1-point on the fourth attempt (global manipulatory strategy). No points were given if the child could not locate the figure. The results revealed that, overall, children's ability to disembed was improved through training. Children who participated in the Shape Disembedding training program scored significantly higher than those in the Water-Level program and the control group. The increase in scores was due to children shifting from the global manipulatory strategies or no strategy in the pretest to using the successive and external successive strategies in the posttest. Therefore, the children had learned to utilize more complex methods of detecting hidden shapes

The aforementioned studies indicate that 6- to 10-year-old children's ability to disembed can be improved through training. To my knowledge, the current literature has not examined training on disembedding amongst children younger the age of six. Questions remain as to whether similar training can improve preschool-aged children's performance on disembedding tasks.

Can training on one type of skill be transferred to other spatial skills?

Everyday experiences in preschool provide opportunities for children to develop a multitude of spatial skills. For example, completing puzzles requires that children engage in both mental rotation and disembedding. Building with blocks, another typical preschool activity, requires multiple spatial skills as well. When exploring with blocks, children must locate specific pieces for complex structures while physically rotating and stacking objects. Thus, one could argue that participating in these types of preschool activities (block building, playing with puzzles, etc.) may simultaneously enhance multiple components of spatial thinking. As such, training on one type of spatial skills may transfer to other spatial skills.

One reason that training may transfer to other spatial skills is that training can enhance performance in nonspecific ways such as inducing changes in basic perceptual and attentional processes. For example, during learning, a visual stimulus is often surrounded by stimuli that are irrelevant and may impede learning by capturing attention. Selective attention suppresses the irrelevant information, thus providing a mechanism for organizing important information in complex visual scenes. This may increase speed of processing on detecting embedded figures. In addition, researchers have argued that improvements in mental rotation elicited by video game training may be due, in part, to improvements in visual selective attention (Feng, Spence, Pratt, 2007).

Speed of processing is also related to visual working memory (Awh, Vogel, & Oh, 2006). Mental rotation tasks involve a dynamic process in which a participant attempts to mentally rotate one figure to align it with a comparison figure. Part of the mechanism underlying improvement in mental rotation skills is that participants become faster at rotating the objects in their minds (Kail & Park, 1992). This requires efficient scanning of the visual scene and increases in visual working memory. Therefore, when asked to complete a mental rotation task or a disembedding task, working memory is likely to enhance the amount of information that children can think about and act on. This raises questions about whether training on disembedding tasks can enhance performance on spatial tasks involving mental rotation because of increased working memory and flexible attention capacities (shifting focus between multiple figures) underlying the performance of these different spatial skills.

Studies conducted on the transferability of spatial skills with young children are sparse and findings are mixed. Connor, Schackman, and Serbin (1978) explored the effects of training on first grade children's disembedding skills. The sample included 93 first-grade students. The training condition utilized the transparent overlay activity described in the Connor et al. (1977) study. As mentioned, this activity allows children to view an embedded diamond in successively simplified versions by removing layers of the complex figure to reveal the simplified diamond. The control condition did not receive any training. Both groups completed pre- and posttest measures. First, the children completed a set of test items from the CEFT. Next, the children completed the Sternglanz-Lifschitz Folding Blocks Test as a measure of generalization. The task required the children to visually examine various two-dimensional layouts and determine what type of three-dimensional shapes they would form if the two-dimensional layouts were folded such as a cube or a triangular-based pyramid. Overall, both the training and condition groups exhibited an increase in scores on the CEFT. However, the children in the training condition improved more than the children in the control. Although the training was effective in improving both boys' and girls' performances on the CEFT, the training did not generalize to an increase in scores on the folding blocks task.

However, Tzuriel and Egozi (2010) provide some supportive evidence that spatial training can transfer beyond the training task. The goal of their study was to explore the effects of training on first-grade children's mental rotation skills. The sample included 116 children ranging from 6- to 7-years of age. The children were randomly assigned to an experimental group or a control group. The intervention was comprised of eight small group sessions that were 45 minutes each. Every session included four flash cards with different figures printed on them. To begin, children were shown a figure on the overhead projector three times, each time for three seconds. Next, children were asked to draw the projected figure from memory. Finally, children were shown the figures again and guided through the process of piecing apart the image. Children were encouraged to participate in group discussions that prompted them to rotate and look at the figures from different perspectives. The control group was shown the same images but were simply asked to copy the figures rather than draw them from memory. The control group they did not receive group discussion or guidance to reexamine the figures.

The children completed three different tasks for the pre- and posttests. One of the tests was the Spatial Relations subtest from the Primary Mental Abilities–Children's Version (Thurstone & Thurstone, 1962). The Spatial Relations subtest measured the children's ability to make inferences about the relationship between two-dimensional rotated objects. Each test item consisted of a target figure and children were asked to decide which of four figures would complete the target figure. The four alternative figures were presented at varying angles so that the child was required to mentally rotate the figures to complete the target figure. Another test was the Windows Test from the Cognitive Modifiability Battery (Tzuriel, 1995). In this task, children were presented with figures that resembled upright houses. On the houses, there was a 3 x 3 pattern of squares, referred to as “windows” (9 total windows). Some of the windows on the houses were blacked out, as if the curtains were closed, while other windows remain white, as if the windows were open. Children were then shown an identical rotated house with all open windows and asked to mark the windows that were closed to match the upright house. The latter test was considered to include task characteristics that were related to the intervention.

The results associated with the Windows Test showed that the experimental group scored significantly better than the control groups and showed much higher improvement. The results for the Spatial Relations subtest were very similar to those found for the Window Test. Therefore, the intervention was successful in helping children solve two different spatial tasks involving mental rotation, one of which was not directly related to the instruction in the intervention. These findings suggest that training that provides a variety of opportunities to participate in spatial tasks may increase the prospect of transferability. In the present study, children were exposed to shapes in different orientations, which enabled children to view the shapes from different perspectives. Hands-on activities also provided children with opportunities to physical manipulate shapes. A question of interest was whether the curriculum improved children’s mental rotation skills as well as disembedding skills given the multitude of activities that involved both these components of spatial skills.

Children’s background characteristics and spatial skills

Little attention has been paid to the question of how children’s background characteristics are associated with their spatial skills. Meta-analytic reviews, which have largely focused on adults and older children, provide convincing evidence that there is a substantial male advantage on mental rotation tasks, and that this sex difference is larger than that for other aspects of spatial cognition (Voyer, Voyer, & Bryden, 1995; Uttal et al., 2013). On many mental rotation and mental transformation tasks, boys outperform girls (Johnson & Meade, 1987; Tzuriel & Egozi, 2010), even among 4- and 5-year-old children (Ehrlich, Levine, & Goldin-Meadow, 2006; Levine et al., 1999). For example, Casey et al. (2008) found that boys in kindergarten outperformed their female counterparts on a mental rotation task that utilized 3D blocks. One explanation for the male advantage is that boys spend more time manipulating, rotating, and exploring objects through activities such as playing with blocks and trucks (Fagot & Patterson, 1969). Girls may have less opportunity to learn and practice these abilities because their playtime typically includes activities that deal less with manipulatives such as art and dramatic play.

There are mixed findings as to whether there are developmental gender differences in disembedding skills. In one study, Coates (1974) found that 3- to 6-year-old girls out performed boys on the Children's Embedded Figures Test. In contrast, Connor (1978) found that first grade boys performed better than the girls did and this difference was mitigated after the children participated in a training lesson that focused on locating embedded figures. In another study, Kaplan and Weisberg (1987) found that third grade female students outperformed their male counterparts on a task that measured their ability to locate embedded figures. However, fifth grade boys in the same study outperformed the girls. Several other studies suggest gender differences in disembedding skills are not present amongst children until 8 years of age (Bigelow, 1971; Bowd, 1976; Goodenough & Eagle, 1963; Pennings, 1991). A meta-analysis of sex differences suggested that differences on the embedded figures tasks do not emerge until the age of 14 years (Voyer et al., 1995).

To my knowledge, little information in the literature exists regarding the association between socioeconomic status (SES) and children's spatial abilities. In one study, Levine et al. (2005) examined spatial ability amongst 2nd and 3rd grade children from varying socioeconomic backgrounds. The children were classified as either low, medium, or high-SES depending on the reported income ranges for the neighborhood that their school was located. The children were tested four times over a two-year period. The three tests utilized were a syntax comprehension task, a mental rotation task, and a map comprehension task. The syntax comprehension task required the children to choose a picture that corresponded with a sentence read from a story. The mental rotation task required the children to select a figure that would complete a target figure. Lastly, the map comprehension task required the children to select the map that indicated where a star was located in a separate photograph. Levine and colleagues report a significant effect of SES on each of the three tasks. Further, it was reported that high and middle SES children performed significantly better than did children from low SES schools. The findings provide evidence that socioeconomic factors such as education and income are related to performance on spatial tasks.

In a more recent study, Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, and Chang (2014) explored the relationship between SES and spatial skills amongst 3-year-old preschool children. The sample included 102 children. SES was based on maternal education level. Children with mothers who had completed high school or an associate's degree were considered low SES while children with mothers who had completed a bachelor's or graduate degree were considered high SES. About half of the children were categorized as low SES and the other were categorized as high SES. All of the children completed a test of spatial assembly developed for the purpose of the study. During this task, children were shown a 3D model made of large interlocking block pieces. Children were then given a matching set of blocks and asked to make their pieces match the model. Each task item included two to four blocks. Children received one point for matching the model with complete accuracy. Children were also scored based on the number of errors that they made related to rotation, translation, and vertical rotation of pieces. Overall, it was found that low SES children performed significantly worse on the spatial task than did high SES children. Taken together, these studies suggest that socioeconomic factors such as maternal education and income impact the development of some early spatial abilities. Further investigation is needed to determine if a similar relationship exists between SES and the spatial skill of disembedding.

The present study

The general goal of the present study was to develop, implement, and test the effectiveness of a curriculum that I designed to improve disembedding skills among 4-year-old preschool children. This study expanded on typical geometry instruction by integrating training on disembedding abilities into lessons focused on teaching children about shape attributes. The rationale for integrating disembedding training in a shape properties curriculum is supported by the work Pennings (1991). The researcher found that exposure to a curriculum that encouraged hands-on exploration of shapes resulted in improved performance on an embedded figures test amongst 7- to 8-year-old children. Further, several studies have shown that certain types of play activities enhance spatial thinking because they require children reason about spatial relationships (Coates et al., 1975; Levine et al, 2012). For example, Robert and Heroux (2004) found that children who participated in spatial manipulation play activities (e.g., cutting and folding paper, fitting blocks into holes, and "finding the hidden object" games) in early childhood performed better on visuo-spatial tasks later on. Thus, the intervention curriculum utilized in this study provided a variety of activities that encouraged hands-on exploration of shapes with the goal of improving preschool aged children's ability to disembed.

The present study also explored whether training on disembedding shapes would transfer to mental rotation skills. Although children were not explicitly trained to mentally rotate shapes, they were provided with opportunities to examine shapes from varying orientations and participate in hands-on activities that enabled them to manipulate and rotate shapes. Thus, it was possible that the dynamic nature of the activities would improve the skill of mentally rotating shapes in general.

Standard measures of disembedding skills (classified as an intrinsic-static) and mental rotation skills (classified as an intrinsic-dynamic) were utilized in this study. To date, the CEFT has been the primary task utilized to measure young children's early disembedding abilities, but the task was developed for children 5 years and older. Thus, two new measures were developed for the purpose of this study: (1) A Visual Search Shape Task that required children to scan a scenic diagram to locate shapes of different sizes, orientations, and skews within a specified amount to time; and (2) An Embedded Puzzle Task that required children to matched a rotated puzzle piece to an identical one in a puzzle template. These new measures were modeled after play activities that are typical in preschool classrooms such as solving puzzles and playing visual search games (e.g. "I Spy" and "Where's Waldo?"). Both of these new measures required disembedding and mental rotation skills that straddled the intrinsic-static and intrinsic-dynamic dimensions. These new measures assessed improvement in disembedding as well as transferability of training to mental rotation skills.

The pretest provided an opportunity to examine the construct validity of these newly created measures by examining how children's scores on the new measures correlated with the scores on the standard measures. Significant correlations would help confirm that the newly created measures had elements in common with the standard measures. Moreover, the diversity of the children included in this study allowed for the exploration of performance on various spatial reasoning tasks associated with children's background characteristics, namely, primary language, home language environments, maternal years of education (a proxy measure of SES), and age of preschool entry.

The following research questions were addressed:

(1) How did pretest scores obtained from the various spatial tasks correlate with one another?

(2) How were children's background characteristics- language background, maternal education, and years of preschool education- associated with the pretest scores on the various spatial tasks?

(3) Were there differences between the treatment group of children, who participated in a shape-disembedding curriculum, and the control group of children, who were exposed to lessons focused on shape recognition, in performance on the various spatial tasks and the shape knowledge measure?

Chapter III

Methods

Participants

Forty-five children (23 boys and 22 girls) were recruited from preschools in the California Central Coast region. All of the children were 4-years-old (M = 4.47 years, SD = .26). Due to scheduling issues, five children who completed the pre-test measures did not partake in the curriculum. The treatment group included 20 children, 9 boys and 11 girls (M= 4.48, SD= .27) and the control group included 20 children as well, 10 boys and 10 girls (M= 4.50, SD= .27).

Approximately 80% of the children spoke English as their primary language and the remaining 20% spoke Spanish as their primary language. Information regarding their mothers' education level and how many years the child had been in preschool were also collected. Forty-seven percent of parents had completed high school, 13% trade school or an associates degree, 22% a bachelors degree, 5% a graduate degree, and 13% declined to answer. Eleven percent of the children began preschool at or before one-year of age, 16% at the age of two, 43% at the age of three, and 30% at the age of 4.

Procedure

Before beginning the study, a letter explaining the purpose was given to the directors of the preschools, who in turn, gave it to the teachers. The teachers then distributed the consent letter to parents of children in their classes. The letter described the purpose of the study and explained the design. It also included a demographics questionnaire for parents to complete. The parents returned the consent forms to the child's teacher and testing began approximately one week later.

Children whose parents had returned the signed consent form were invited to participate in the pre and post-test interviews as well as the curriculum. Verbal assent from each child was received prior to testing. A graduate student researcher interviewed the children one at a time and an undergraduate student operated the camera and assisted with set-up. The interviews were conducted in the child's classroom or outdoor play areas. The interviews were audio and video recorded and lasted approximately 15 minutes for both pre and post-testing. After each activity, children had the opportunity to choose a sticker whether they completed the activity or not. All measures were later scored.

Both the treatment and control curriculum consisted of three lessons that lasted approximately 25-minutees each. The lead researcher taught both the treatment and control curriculum. An undergraduate student assisted with operating the camera and sitting with the children during the lessons. The curriculum was taught at a table inside the children's classroom in small groups of four to six children. Each lesson consisted of two or three activities. Because the lessons were taught inside the classrooms, there was occasionally other children around or loud noises in the background. Every attempt was made to create a quiet and comfortable learning experience by the classroom teacher and researchers.

Children were assigned to either the treatment or control curriculum based on attendance (not all of the children attended everyday which limited random assignment). On the first day of instruction, the first four to six children present that day received the treatment curriculum. The next four to six children present received the control curriculum, alternating between the two instructional designs thereafter. If a child was absent for one of the lessons, the researcher returned the next day to conduct a makeup lesson with that child.

The lessons for both treatment and control were completed within seven days of the first lesson. Post-testing was conducted two to five days after the last lesson.

Measures

General Shape Knowledge (GSK). Children's general shape knowledge was assessed with a task utilized by Clements et al. (1999). The children were presented with four, 8 ½ by 11-inch sheets of papers that contained line drawn shapes. Each sheet presented valid and invalid instances related to one type of shape, either squares, rectangles, circles, or triangles. Figure 8 shows the triangle knowledge test. Valid instances were considered shapes that had straight sides and pointed vertices (triangles, rectangles, and squares) or were perfectly round (circles). Valid instances had variations in prototypical and non-prototypical forms, in different rotations, skews, and sizes. Invalid instances included shapes with rounded sides, concave sides, or open sections. Examples of valid triangles in Figure 8 are numbers 1-3, 6, 8, 12-14, and 16. Examples of invalid instances in Figure 8 are figures numbered 4, 5, 7, 9, 10, 11, 15, and 17. Using a marker, the children were asked to place a mark on each figure that represented a triangle. Each sheet was presented one at a time, and for each sheet, the children were told to let the experimenter know when they had marked all instances of the target shape. Some of the children pointed to a specific shape and asked if it was a valid instance. The experimenter responded by saying, "If you think it's a ____, put a dot on it." Some of the children also asked what a specific shape looked like. For example, if a child asked what a rectangle was, the experimenter would respond by giving a basic definition such as "A rectangle has two long sides and two short sides." If after 30 seconds the child was still looking for instances of the given shape, the experimenter prompted the child and began the next shape. Each test was scored for the number of correctly identified shapes as well the number of errors. An error was considered an invalid shape, such as a triangle with concave sides.

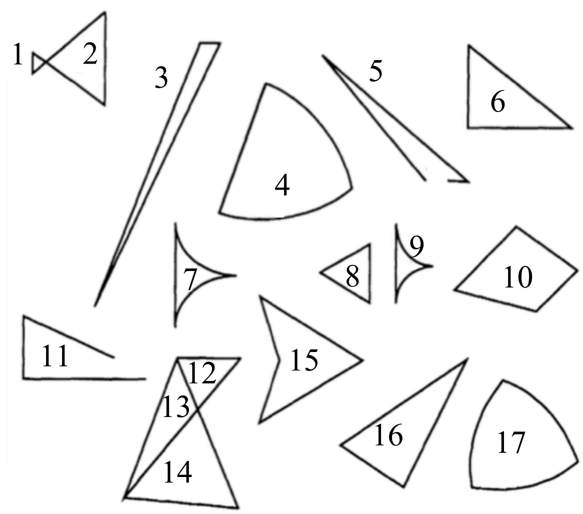


Figure 8. Triangle shape knowledge test from Clements et al. (1999).

Children's Embedded Figures Test (CEFT). All of the children completed the CEFT developed by Karp and Konstadt (1971). The CEFT was developed for children between the ages of 5- and 9-years-old. However, it was implemented in this study with 4-year-old children because the embedded figures test designed for younger children, the Preschool Embedded Figures Test (Coates, 1972), is no longer available. The CEFT consists of 25 test items however; the children in the present study were tested on six diagrams to minimize mental fatigue. Also, because the images were drawn over 40 years ago, it was possible that the outdated items were not recognizable to the children. The experimenter determined which images were considered outdated and excluded them from the test. For example, the image of a teakettle, a grandfather clock, and a sled were removed. Karp and Konstadt (1971) intended the test items to progress from easy to difficult. Therefore, test items were included from the beginning, middle, and end of the original test. Examples of the diagrams used include images of a boat (T1), a doll (T2), a house (T3), a teepee (T6), a butterfly (T9), and a stroller (T11). Figure 9 provides examples of images from the CEFT.

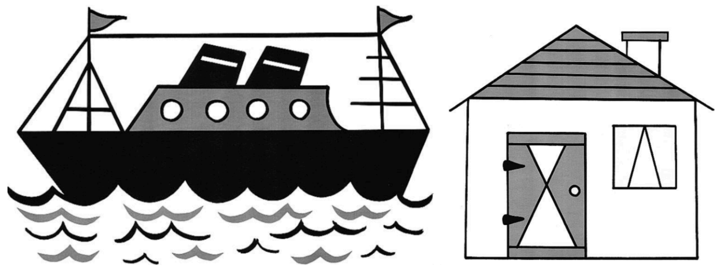


Figure 9. Example images from the CEFT (Karp & Konstadt, 1971).

The test consisted of a discrimination item, a demonstration series, one practice item, and six test items. To begin, the children were shown the discrimination item. The discrimination item consisted of four printed triangles on a piece of paper. The triangles were of different sizes and skews with an equilateral triangle as the target shape. The experimenter presented the paper to the children along with a paper cutout of the target triangle and asked, “Can you trace the triangle that matches my triangle?” Children were prompted to trace the triangle they chose as well as place the triangle cutout on top of their choice to determine if it was a match. The experimenter then prompted the children to put the cutout over each triangle to show that there was only one “perfect match.” For example, children were shown that one triangle was too small so it was not a perfect match. After the discrimination item, children participated in the demonstration series. The demonstration series consisted of three incomplete pictures to help illustrate the process of disembedding. Children were first shown a simple figure with the target triangle embedded in it. Children had the opportunity to locate, trace, and compare the triangle to determine if it was a match. Children were then shown the same figure with a few more details added and asked to locate the same triangle. Finally, children were shown the same figure with complex detail, creating a complete image of a truck, and were then asked to locate the target triangle again. The process of disembedding became more complex with each successive picture. After the demonstration series, children completed one practice item. The practice item required the children to disembed the target triangle from the image of a clown. The cutout triangle was left on the table but children were encouraged to trace the triangle before comparing it. Children were not scored on the discrimination item, demonstration series, or practice item.

For each of the six test items, children were presented with diagrams of familiar everyday objects. The triangle cut out was removed from the table so that children had to locate the target triangle from memory. For each test item, the interviewer asked the children to find the target triangle in the image and trace it with their finger. There was no time limit per diagram on the version utilized in the current study. Children received 1 point for each correctly identified shape for a total of six points possible. The experimenter also noted whether the child found a triangle other than the target triangle. For example, in Figure 9, the experimenter noted if the child located the triangle in the window of the house in as opposed to the target triangle located at the bottom of the door.

Children's Mental Transformation Task (CMTT). The children took part in a 2D mental rotation task adapted from Levine, Huttenlocher, Taylor, and Langrock (1999) called the Children's Mental Transformation Task (CMTT). The CMTT is a spatial task that assesses children's ability to mentally rotate and translate figures. The original task consisted of 32 problems, including 16 mental translation and 16 mental rotation test items. There are four different forms of the CMTT. Each form consists of the same test item images but includes different rotations and translations for each target shape. For the purpose of this study and to minimize mental fatigue, the first eight mental rotation test items from Form A, Oder 1 were included.

In this task, children were presented with a shape that was split into two halves and asked to determine what shape would be made if the two halves were combined. The experimenter used gestures to demonstrate the two halves moving together. Specifically, the experimenter said, “Look at these pieces and look at these pictures. If you put these pieces together, they will make one of the pictures. Point to the picture that the pieces make." The two pieces were rotated at varying degrees, requiring the children to mentally rotate the images to combine them and create a complete shape. The children were asked to identify which of four complete shapes the two halves would make when combined (See Figure 10). There was no time limit for each test item and children received 1 point for each correct response. There were no practice items.

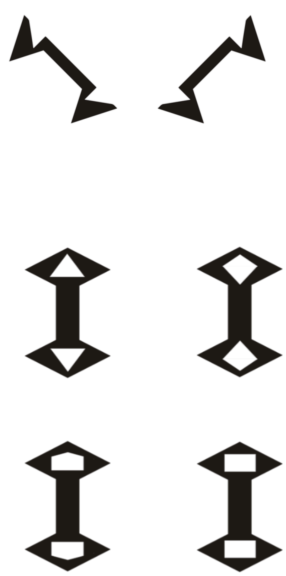


Figure 10. Example test item from the CMTT (Levine et al., 1999).

Visual Shape Search Task (VSST). The Visual Shape Search Task was developed for the purpose of this study. It assessed children's ability to simultaneously disembed and rotate shapes in a timed-task. Two visual scenes were presented to the children on 8 ½ by 11-inch sheets of paper. One scene depicted a beach with hidden triangles (See Figure 11) and the other scene depicted a play area with hidden rectangles (See Appendix C). Children were instructed to find as many triangles as they could within a 30-second time period. They were then asked to do the same for the play scene with rectangles. The children were given a marker and asked to put a dot on each target shape they found. A 30- second sand timer was visible to the children so that they were aware of how much time they had left for each task. The 30-second time period was chosen to give the children enough time to familiarize themselves with the task but not so much time that the children located all of the shapes. There were no practice items.

Children received one point for each correctly identified prototypical or non-prototypical triangle and each correctly identified prototypical or non-prototypical rectangle. Children were also scored on the errors they made such as choosing a rectangular shape with rounded corners. This was done to account for children who chose invalid instances of shapes as well as children who randomly put dots all over, regardless of shape.

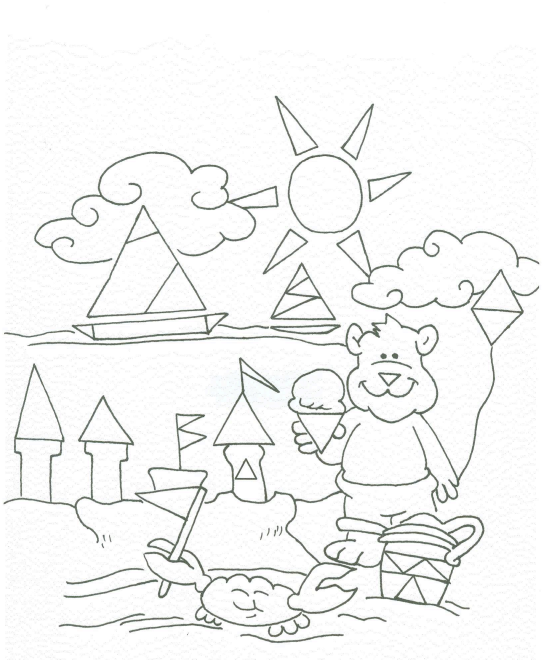


Figure 11. Triangle Visual Shape Search Task.

Children's Rotated Embedded Puzzle Task (CREPT). To assess children's ability to simultaneously disembed and mentally rotate, children took part in a puzzle-piece matching task newly designed for the purpose of this study. The children were shown 2-D puzzle templates of familiar objects. The puzzle templates had lines that pieced apart the image into puzzle pieces (See Figure 12). The five puzzle templates were presented in order of the number of pieces, beginning with a four-piece puzzle and concluding with an eight-piece puzzle. Children received one point for each correct response, summed for a total of five points possible. The displayed puzzle piece cutouts were presented at various angles requiring children to mentally rotate the pieces to find their matches in the templates. Item 1 was presented at a 90-degree angle, Item 2 at a 180-degree angle, Item 3 at a 90-degree angle, Item 4 at a 180-degree angle, and Item 5 at a 90-degree angle (See Appendix D).

The children participated in two practice trials before the test began. During the practice trials, the experimenter presented a puzzle piece cutout alongside the corresponding puzzle template and prompted the children, “Point to where this puzzle piece belongs.” Children were encouraged to point to where they thought the piece belonged before comparing it to the puzzle piece cutout. The experimenter demonstrated how the puzzle piece cutouts lined up with their matches in the template by physically rotating the piece to match. Children were given the opportunity to choose another location if their first and second choices were incorrect. Thereafter, the children completed 5 test items.

For the test items, the children were told that they could not move or rotate the puzzle piece cutout with their hands. The children were repeatedly reminded to use “their brain to turn the puzzle piece.” The number of puzzle pieces for the templates ranged from 4 to 8 pieces. For each image, a puzzle piece was displayed alongside the template puzzle and the children were asked to find its match in the template.

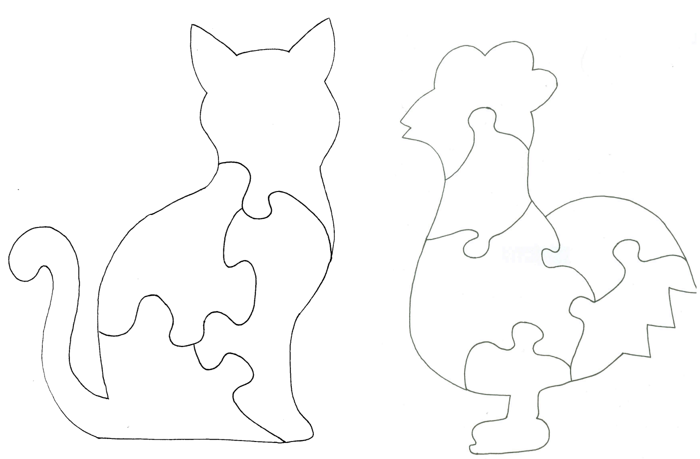


Figure 12. Example test items from the Children’s Rotated Embedded Puzzle Task.

Intervention

The present study included one treatment curriculum and one control curriculum. Both curriculums consisted of three 25-minute lessons. Each lesson included two to three activities that encouraged the children to learn about and explore shapes using a variety of mediums (See Appendix A). Shape instruction in preschool typically involves introducing children to prototypical forms of shapes that do not provide instances to learn about non-prototypical shapes (Clements, 2004). Children accurately classify prototypical shapes as exemplars of their respective categories but as a result of their limited exposure to non-prototypical shapes, they tend to reject shapes in the same category that differ in skewness, aspect ratio, and orientation (Clements, Battista, & Sarama, 2001). Thus, both conditions were exposed to shape exploration to strengthen their basic understanding of shapes. However, the treatment condition utilized the basic shape activities as a foundation for disembedding while basic shape understanding was the main focus of the control condition. Children were encouraged to respond to and ask questions as they participated in the activities. All lessons were video recorded.

Treatment Curriculum. The treatment curriculum provided opportunities for children to explore the concept of embedded figures through hands on activities. The key concepts covered in the treatment included: (1) defining attributes of 2D plane figures, (2) defining attributes of 3D geometric solids, (3) overlapping figures and the shapes created within them, and (4) "hidden" or embedded figures. The activities presented in the treatment curriculum were organized to ensure that children built upon concepts that were explored in previous lessons. The lessons were based on an intervention program developed by Pennings (1991) that improved second graders ability to disembed shapes.

Lesson 1 focused on providing children with the opportunity to experiment with 2D shapes and introduced the concept of hidden or embedded figures. The lesson began by asking the children to name shapes that they were familiar with. Once the children had listed four or five shapes, the experimenter placed pipe cleaners on the table and prompted the children to make shapes by bending and combining them. The experimenter encouraged children to discuss defining attributes of the shapes they were making. For example, as a group, the children were encouraged to generate a definition of a square by discussing that a square has four straight sides and four vertices. Each group discussed defining features and attempted to make circles, squares, triangles and rectangles. Next, the children played a shape game that required them to identify instances and non-instances of basic shapes. A doll, named Celia, was introduced to the children. The children were told that Celia enjoys learning about shapes and needs help choosing shapes for her art project. The children were also told that Celia only wanted circles, squares, triangles, and rectangles for her art project. If the figure was a valid instance of one of the shapes, the children placed the shape in front of Celia. If the figure was not a valid instance, it was put aside. This activity encouraged children to discuss why a shape was a valid or invalid instance by bringing their attention to defining features.

Children were given the opportunity to look at both prototypical and non-prototypical shapes as well as invalid shapes with concave edges, open sides, or rounded corners. The experimenter asked probing questions such as "How do you know it's a circle?" or "How is this rectangle different from the square?" The last activity introduced children to the concept of embedded figures. In this activity, the children used circles, squares, triangles, and rectangles to create a sailboat. The experimenter first showed the children pictures of sailboats and brought their attention to how some of the parts of a sailboat looked like shapes such as the sail looking similar to a triangle. Children then glued the shapes down to create their own image of a sailboat. For example, children used a long rectangle for the base of the sailboat and circle for the windows.

The second lesson provided opportunities for the children to interact with 3D geometric solids and further explore the concept of embedded figures. The lesson began with a quick sorting game in which the children were asked to sort the examples and non-examples of shapes from the previous lesson. Children were prompted to give an explanation as to why they deemed a shape as valid or invalid. Next, the children explored 3D foam blocks including a pyramid, cube, rectangular prism, triangular prism, and cylinder. One at a time, the experimenter showed the children each 3D foam block by dipping one of its sides in paint and stamping it onto paper. The children were then given the opportunity to stamp and paint with each of the shapes themselves. Children were encouraged to rotate the 3D foam blocks to see what other shapes they could find. This was included to reinforce the idea that plane shapes can be found in 3D foam blocks. For example, a pyramid consists of a square base with four triangle faces. Children were encouraged to rotate, flip, and physically explore the shapes while painting. Next, the experimenter showed the children a line-drawn image of a house to transition to a disembedding activity. The experimenter asked the children to locate shapes within the house. Each child was given the opportunity to name one shape. If the children missed any of the shapes, the experimenter traced them to draw the children's attention to them. The house included shapes such as a triangle roof, a rectangle door, and square windows. Lesson 2 also included an activity that required the children to fill in the outline of a train with pre-cut basic shapes, such as squares, triangles, circles, and rectangles.

Each child was given a piece of paper with the outline of a train. The children were also given a variety of shapes and were then prompted to explore which shapes fit where. For example, a circle fit in the place of the wheels. Children did not glue the pieces down so that they could move them around as needed. This activity was included to reinforce the concept that shapes can be found within different images.

The last lesson, Lesson 3, focused solely on the concept of embedded figures. The lesson began by prompting the children to look around the room to find “hidden” shapes. The experimenter reminded the children of the hidden shapes from previous activities such as the rectangle door in the house and the circle windows on the sailboat. The children were then encouraged to get up one at a time and show the rest of the group a shape they had found embedded somewhere in the classroom. Next, children’s attention was drawn to a drawing of a train that had many small embedded shapes. The children spent time looking at the train to disembed hard-to-find shapes such as a small skinny rectangle in the spokes of the tires. In the next activity, children were encouraged to play with a toy fire truck and a toy house. While interacting with the toys, the experimenter asked the children if they could find any hidden shapes. The children took turns locating shapes and playing with the toys. The children were also encouraged to rotate the toys to see if looking at the toy from a different angle helped them locate other shapes. The last activity was a game (Color Code) that used transparent overlays to create complex figures consisting of embedded shapes. The children were told that they had to act like detectives to find the hidden shapes. One at a time, each child looked through a booklet consisting of various images that coincided with the transparent overlays. Once the child had decided on an image they wanted to complete, they looked through the transparent overlays to determine which ones had to be combined to recreate the image. Most of the images required two to four overlays. Children also had to consider which direction and what order to place the overlays down in. All of the children were given two opportunities to create an image from the booklet and one opportunity to make up their own image. This activity reinforced the concept that shapes can be found within complex images.

Control Curriculum. The overall goal of the control curriculum was to encourage basic shape understanding and to provide opportunities for free play with shapes. The experimenter provided less prompting and less detail during each of the shape activities compared to the treatment curriculum.

Lesson 1 began with a similar pipe cleaner activity used in the treatment. The experimenter began by asking the children what shapes they knew and then allowed the children to play with the pipe cleaners. However, the children were not prompted on how to make specific shapes and were allowed to make anything they wanted with the pipe cleaners. Next, the children played the shape sorting game utilized in the treatment curriculum that required them to identify instances and non-instances of basic shapes. The doll named Celia was introduced to the children and the children were asked to help Celia choose shapes for her art project. The children were also told that Celia only wanted circles, squares, triangles, and rectangles for her art project. If the figure was a valid instance of one of these shapes, the children were placed the shape in front of her. If the figure was not a valid instance, it was put aside. This activity remained the same as the treatment because one of the goals of the control curriculum was to teach children about the features of basic shapes. Lesson 1 concluded with an activity that required the children to color a train worksheet. The train image on the worksheet consisted of different shapes but the children's attention was not drawn to them. The children were given crayons and simply instructed to color in the train.

Lesson 2 focused on free play with 3D geometric solids. The lesson began with a quick sorting game in which the children were asked to sort the examples and non-examples of shapes from the previous lesson. Next, the children were given a variety of wooden blocks to build with. The experimenter asked probing questions such as, "What are you building?" but did not discuss shapes with the children. The last activity included the same 3D foam blocks from the treatment curriculum. During this activity, children were given the 3D foam blocks, paint, and paper. The children were encouraged to paint using the blocks. No further shape concepts were prompted by the experimenter during the activity.

Finally, Lesson 3 began with the same shape sorting game from the previous lesson. Afterwards, children traced shapes on a worksheet. The worksheet had line-drawn instances of circles, squares, triangles, and rectangles. The children were given a marker to trace the dotted lines with. Free play with tangrams was included as the last activity. Children were given the tangrams and encouraged to make a picture or build with them. No further shape concepts were prompted by the experimenter.

Chapter IV

Results

Preliminary analyses

GSK. Total scores were computed for each child's responses on the circle, square, triangle, and rectangle tasks. In order to account for errors, each child's incorrect responses were also summed and subtracted from their total score. Because responses on the GSK task were not binary, the proportions of shapes found were computed for each shape. Rectangles were not included in the analyses because there were only two correct instances of rectangles for children to choose from (out of 15 possible choices), providing children with little opportunity to succeed on the task (M = -1.39, SD = 1.66). Children scored highest on the circle task (M = .83, SD = .27), indicating that children were better at identifying circles than squares (M = .68, SD = .24) or triangles (M = .24, SD = .23). Paired samples correlations revealed a moderate and positive correlation between the percentage of circles and triangles correctly identified (r= .36, p =.02). Further, paired samples t tests revealed that there was a significant mean difference between circles and squares ($t(44) = 3.03$, $p = .004$), circles and triangles ($t(44) = 14.08$, $p < .001$), and squares and triangles ($t(44) = 9.77$, $p < .001$). This indicates that on average, children located significantly more circles than squares or triangles. Also, children correctly identified significantly more squares than triangles, indicating that triangles were the most difficult for children to identify. A composite score was computed by combining the average percentages from the circle, square, and triangle tasks to be utilized for the remaining analyses.

CEFT. Item analysis was utilized to determine reliability and validity for the CEFT. Item difficulty assessed the proportion of children that answered each item correctly. Test

Item 6 was removed from the analyses because only one child correctly identified the target triangle, indicating that the item was developmentally inappropriate for the sample population. Once Item 6 was removed from the analyses, the overall average item difficulty increased from .39 to .46, indicating that the test was of average difficulty for the children to complete. Item discrimination was included to assess the extent to which the test discriminated between children who performed well overall and children who performed poorly overall. The average discrimination index score was .65, indicating acceptable discrimination between high and low scorers. The Kuder-Richardson Formula 20 (KR-20) was also utilized to assess reliability and consistency of test items. The KR-20 for the five test items was .52, indicating moderate internal consistency.

The 5 test items included in this analysis appear to follow a developmental trend with 68.9% of the pre-test children correctly locating the target triangle in Item 1 ($M = .69$, $SD = .47$) and 6.7% of the children correctly locating the target triangle in Item 5 ($M = .07$, $SD = .25$). This indicates that the test became progressively difficult from Item 1 to Item 5. As a secondary analysis, the scores were recoded to include cases in which children located valid instances of triangles that were not the target triangle. Children received credit if the triangle had three straight sides and three vertices. For example, 33% of children located the target triangle for Item 4 while 56% of children failed to locate the target triangle but located another instance of a valid triangle. Combined together, 89% of the children who completed the CEFT were successful at locating a valid triangle on Item 4. This provides evidence that children have an understanding of what a triangle is but had difficulty locating the target triangle on some of the test items, specifically Item 4 and Item 5. The proportion of target triangles, valid instances of triangles, and a combined total of both the target and valid instances are presented in Table 2.

Table 2

Mean Score Proportions for Target Triangles, Valid Triangles, and Overall Total

	Target Triangle	Valid Triangle	Total
Item 1	.69	.02	.71
Item 2	.58	-	.58
Item 3	.62	.39	1.00
Item 4	.33	.56	.89
Item 5	.07	.11	.18

CMTT. Two children were removed from the CMTT analyses because they exhibited distracting behaviors or confusion during the task. The remaining scores from 43 children were included in the item analysis to determine reliability and validity for the CMTT. Item discrimination was included to assess the extent to which the test discriminated between children who performed well overall and children who performed poorly overall. A discrimination index of .09 was reported for Test Item 3, indicating that children who performed poorly overall did better on Item 3 than children who performed better overall. Thus, Item 3 was removed from the remaining analyses. After Item 3 was removed from the analyses, the overall average discrimination index increased from .39 to .43, indicating a low, but acceptable discrimination between high and low scorers considering the task consisted of only seven test items. Item difficulty assessed the proportion of children that answered each item correctly. The average item difficulty was .39, indicating that the test was moderately difficult for the sample of children. The KR-20 was also utilized to assess reliability and consistency of test items. The KR-20 for the five test items was .54, indicating moderate internal consistency.

The 7 test items included in this analysis did not follow a developmental trend. For example, 23% of children successfully completed Item 4 while 40% of children successfully completed item 6. Further, there was no significant difference between children's ability to mentally rotate figures that were horizontally or diagonally rotated, $t(43) = .45$, $p = .66$.

VSST. Because responses on the VSST were not binary, the proportions of shapes found were computed for prototypical and non-prototypical triangles and prototypical and non-prototypical rectangles. Paired samples correlations revealed a moderate and positive correlation between the percentages of prototypical and non-prototypical triangles ($r = .41$, $p = .003$) and between prototypical and non-prototypical rectangles ($r = .31$, $p = .04$). In addition, paired sample *t*-tests revealed that there was a significant mean difference between prototypical and non-prototypical triangles ($t(45) = 9.43$, $p < .001$), and prototypical and non-prototypical rectangles ($t(45) = 8.97$, $p < .001$). This reveals that on average, children located significantly more prototypical triangles (M = .58, SD = .18) and rectangles (M = .61, SD = .24) than non-prototypical triangles (M = .31, SD = .19) and rectangles (M = .30, SD = .12). There was no significant difference between the overall proportion of triangles and the proportion of rectangles found. A composite score was computed by combining the average percentages from the triangle and rectangle visual search tasks to be utilized for the remaining analyses.

CREPT. Item analysis was utilized to determine reliability and validity for the CREPT. There were a total of five items included in the task. Item difficulty assessed the proportion of children that answered each item correctly. The overall average item difficulty was .53, indicating that the test was of average difficulty. Item discrimination assessed the extent to which the test discriminated between children who performed well overall and children who performed poorly overall. The average discrimination index score was .72, indicating satisfactory discrimination between high and low scorers. The KR-20 was also utilized to assess reliability and consistency of test items. The KR-20 for the five test items was .52, indicating moderate internal consistency.

Although the CREPT was designed to follow a developmental trend, it appears that Item 1 (M = .44, SD = .50) and Item 2 (M = .49, SD = .51) were more difficult than Item 3 (M = .60, SD = .50) and Item 4 (M = .69, SD = .47). This indicates that the number of pieces in the puzzle does not account for the differences in scores. A secondary analysis was conducted to determine whether the rotation of the puzzle piece affected how children performed on the task. Children performed better on test items that included puzzle pieces that had been rotated at 180 degrees (M = .59, SD = .34) as opposed to 90 degrees (M = .50, SD = .35), however this difference was not significant.

Correlations among spatial skill task scores

A series of correlations were conducted to examine the associations among the task scores. Table 3 presents the correlation coefficients. The GSK was significantly correlated with the CEFT (p = .05), the VSST (p = .001), and the CREPT (p = .001). This indicates that children who recognized more circles, triangles, and squares on the GSK also performed better on the two newly developed static-intrinsic tasks. Children's scores on the CMTT (standard mental rotation task) were significantly positively correlated with the new CREPT, p = .02, meaning that children who were better at mentally combining two rotated shapes into a whole shape were better at matching a puzzle piece to one on a puzzle template that was rotated at a different angle. This correlation suggests that the two measures had elements of spatial skills in common. Scores on the CREPT were also positively correlated with VVST scores $p = .005$, suggesting that children who were highly skilled at locating shapes in a scenic diagram were also highly skilled at mentally rotating one figure to align it with a comparison figure in the puzzle task. The CEFT (standard disembedding measure) was not correlated with shape recognition nor and any of the spatial skills measures.

Table 3

Correlation Coefficients Associated With Pre-Test Spatial Reasoning Task Scores

	I	II	III	IV.
I. General Shape Knowledge				
II. Children's Embedded Figures Test	.30*			
III. Children's Mental Transformation Task	.15	.24		
IV. Visual Shape Search Task	.47**	.21	.08	
V. Rotated Embedded Puzzle Task	.48**	.16	.36*	.41**

*p <.05;**p < .01

Pre-test associations between background and the spatial skills task scores

Gender. A series of *t*-tests were performed to examine whether there were mean differences in performance on the spatial reasoning tasks between girls and boys. Table 4 presents the means and standard deviations associated with the scores on each of the measures. Girls scored significantly higher (M = 3.14, SD = 1.46) on the CREPT (the puzzle task) than the boys did (M = 2.22, SD = 1.28), $t(43) = 2.25$, $p = .03$. There were no significant gender differences among the remaining variables.

Table 4

Pre-Test Means And Standard Deviations Associated With Skills Measures By Gender

Measures (Max points possible)	Total M(SD)	Boys *M* (*SD*)	Girls *M* (*SD*)
General Shape Knowledge	0.58 (0.17)	0.58 (0.15)	0.58 (0.20)
Children's Embedded Figures Test (5)	2.33 (1.30)	2.35 (1.15)	2.32 (1.46)
Children's Mental Transformation Task (7)	2.74 (1.27)	2.73 (1.49)	2.76 (1.04)
Visual Shape Search Task	0.34 (0.12)	0.33 (0.10)	0.34 (0.15)
Children's Rotated Embedded Puzzle Task (5)	2.67 (1.43)	2.22 (1.28)	3.14 (1.46)*

*$p < .05$

Age. A series of correlation tests were performed to examine whether age was associated with performance on any of the tasks. There were no significant correlations.

Primary language. A series of *t*-tests were conducted to examine whether children whose primary language was English performed differently than did children whose primary language was Spanish. There were no language group differences among any of the measures.

Home language environment. A series of one-way ANOVAs were performed to examine whether there were group differences in the task scores among children raised in an English language home environment, a Spanish language home environment, and a home environment in which both languages are spoken. Table 5 presents the means and standard deviations associated with each of the measures by language environment. There was a significant main effect for the VSST. Post hoc tests revealed that children from English home environments demonstrated more advanced skills at recognizing shapes in drawn scenic diagram compared to children from a monolingual Spanish home environment. There was also a marginally significant difference for the CREPT. Post hoc tests revealed that children from bilingual home environments performed marginally significantly better on the puzzle task than children from monolingual Spanish homes. There were no significant differences between home language and the remaining measures.

Table 5

Pre-Test Means And Standard Deviations Associated With The Score For Each Measure By Home Language Environment

	English *M* (*SD*)	Spanish *M* (*SD*)	English/Spanish *M* (*SD*)	*F*	*p*-value
General Shape Knowledge	0.74 (0.13)	0.59 (0.20)	0.69 (0.20)	1.43	.25
Children's Embedded Figures Test	2.67 (1.32)	2.10 (1.37)	2.08 (1.19)	1.11	.34
Children's Mental Transformation Task	2.67 (1.39)	2.30 (0.95)	3.27 (1.27)	1.60	.22
Visual Shape Search Task	0.39 (0.13)[a]	0.27 (0.10)[a]	0.31 (0.10)	4.12	.02
Children's Rotated Embedded Puzzle Task	2.67 (1.32)	1.80 (1.14)[b]	3.23 (1.59)[b]	3.11	.06

Means that share subscripts are significantly [a] or marginally [b] different from one another.

Maternal years of education. A series of one-way ANOVAs were performed to examine whether maternal years of education were associated with performance on any of the tasks. There was a significant main effect of maternal education associated with performance on the CEFT, meaning that children with mothers from higher education backgrounds located more embedded figures than did children with mothers from lower education backgrounds. Post hoc tests revealed that children with mothers who had completed graduate school performed significantly better than mothers who had completed high school, $F(4, 42) = 4.08$, $p = .008$. Means on the CEFT are plotted in Figure 13. There were no significant differences among any of the remaining measures.

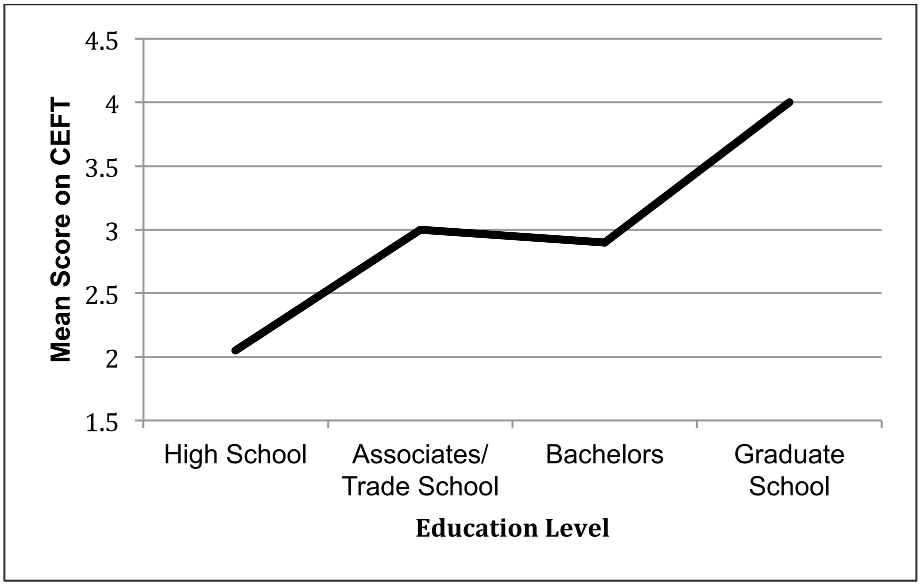


Figure 13. Maternal education level and mean pre-test scores on the CEFT.

Age of preschool entry. The mean age of preschool entry was 2.91 years (SD = 1.11). Table 6 presents the Pearson correlations scores associated with the scores on each of the measures and the age at which the children began preschool. The results indicate that children who began preschool at an earlier age performed better on all of the tasks compared to children who entered preschool at an older age: GSK task ($p = .03$), CEFT ($p = .02$), CMMT ($p = .007$), the VSST ($p = .003$), and the CREPT ($p = .003$).

Table 6

Pearson Correlation Scores Associated With Pre-Test Task Scores And Age At Preschool Entry

	Year of preschool entry
General Shape Knowledge	-.33*
Children's Embedded Figures Test	-.35*
Children's Mental Transformation Task	-.41**
Visual Shape Search Task	-.44**
Rotated Embedded Puzzle Task	-.44**

*p <.05; **p < .01

The Effects of Training on Spatial Tasks

Preliminary Analyses. A chi-square test was performed and showed that gender is equally distributed between the experimental groups, X^2 (1, N = 39) = .03, p = .87. Chi-square tests also revealed that there were no differences between the experimental groups and the primary language spoken at home; X^2 (1, N = 39) = .09, p = .78. T-tests revealed that age (t (32) = .18, p = .86) and education (t(34) = -1.49, p = .15) were also equally distributed across the experimental groups. There were no significant differences amongst boys and girls scores on any of the measures except for the CREPT (boys M = 2.4, SD = 1.10; girls M = 3.30, SD = 1.17). Thus, the analyses for the CREPT included gender as between subjects factor.

GSK. A 2 x 2 mixed ANOVA was conducted with time (pretest vs. posttest) as the repeated measures variable and group as the between subjects factor. This was done to assess whether pre- to post-test scores differed by group (treatment vs. control). Results revealed that there was a significant main effect of time for the GSK (F(1, 40) = 29.63, p < .001). This indicates that the scores at post-test were higher than pre-test scores. Therefore, both types of training were effective at improving children's ability to identify shapes and locate hidden figures. The means for each condition at both time points are plotted in Figure 14. The group by time interaction was not significant for the GSK ($F(1, 40) = .46$, $p = .50$), indicating that the treatment and control groups improved at similar rates.

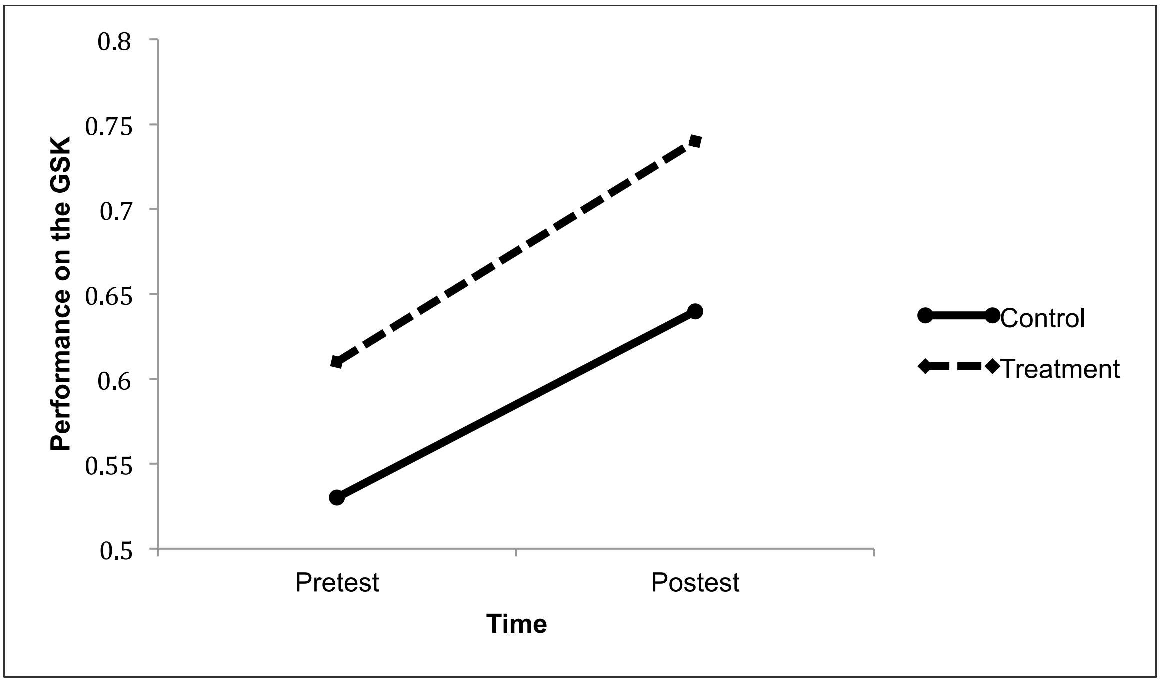


Figure 14. Children's mean score on the GSK in each condition at pre- and post-test.

CEFT. A 2 x 2 mixed ANOVAs was conducted with time (pretest vs. posttest) as the repeated measures variable and group as the between subjects factor. This was done to assess whether pre- to post-test scores differed by group (treatment vs. control). Results revealed that there was a significant main effect of time for the CEFT ($F(1, 40) = 13.24$, $p = .001$. This indicates that the scores at post-test were higher than pre-test scores. Therefore, both types of training were effective at improving children's ability to identify shapes and locate hidden figures. The means for each condition at both time points are plotted in Figure 15. The group by time interaction was not significant for the CEFT ($F(1, 40) = 1.70$, $p = .20$), indicating that the treatment and control groups improved at similar rates.

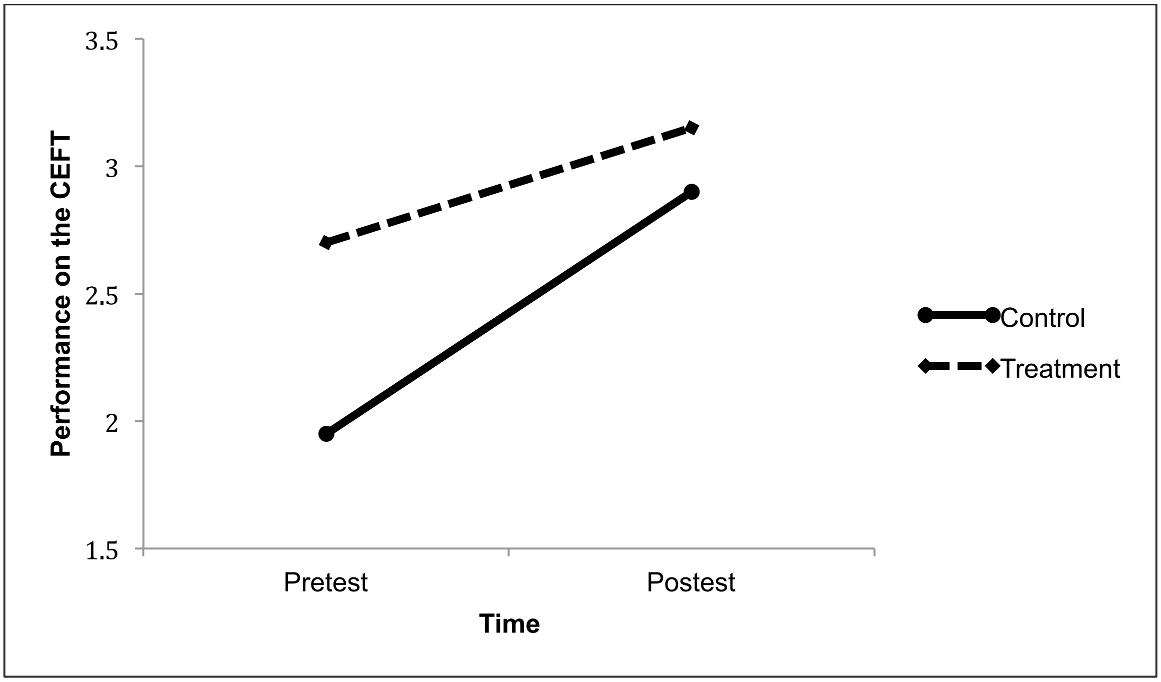


Figure 15. Children's mean score on the CEFT in each condition at pre- and post-test.

CMTT. A 2 x 2 mixed ANOVA was conducted with time (pretest vs. posttest) as the repeated measures variable and group as the between subjects factor. This was done to assess whether pre- to post-test scores differed by group (treatment vs. control). There was no significant main effect ($F(1, 39) = .05$, $p = .82$) or interaction effect ($F(1, 39) = 1.03$, $p = .32$) for the CMTT.

VSST. A 2 x 2 mixed ANOVAs was conducted with time (pretest vs. posttest) as the repeated measures variable and group as the between subjects factor. This was done to assess whether pre- to post-test scores differed by group (treatment vs. control). Results revealed that there was a significant main effect of time for the VSST ($F(1, 40) = 13.22$, $p = .001$). This indicates that the scores at post-test were higher than pre-test scores. Therefore, both types of training were effective at improving children's ability to identify shapes and locate hidden figures. The means for each condition at both time points are plotted in Figure 16. The group by time interaction was not significant for the VSST ($F(1, 40) = 1.67, p = .20$), indicating that the treatment and control groups improved at similar rates.

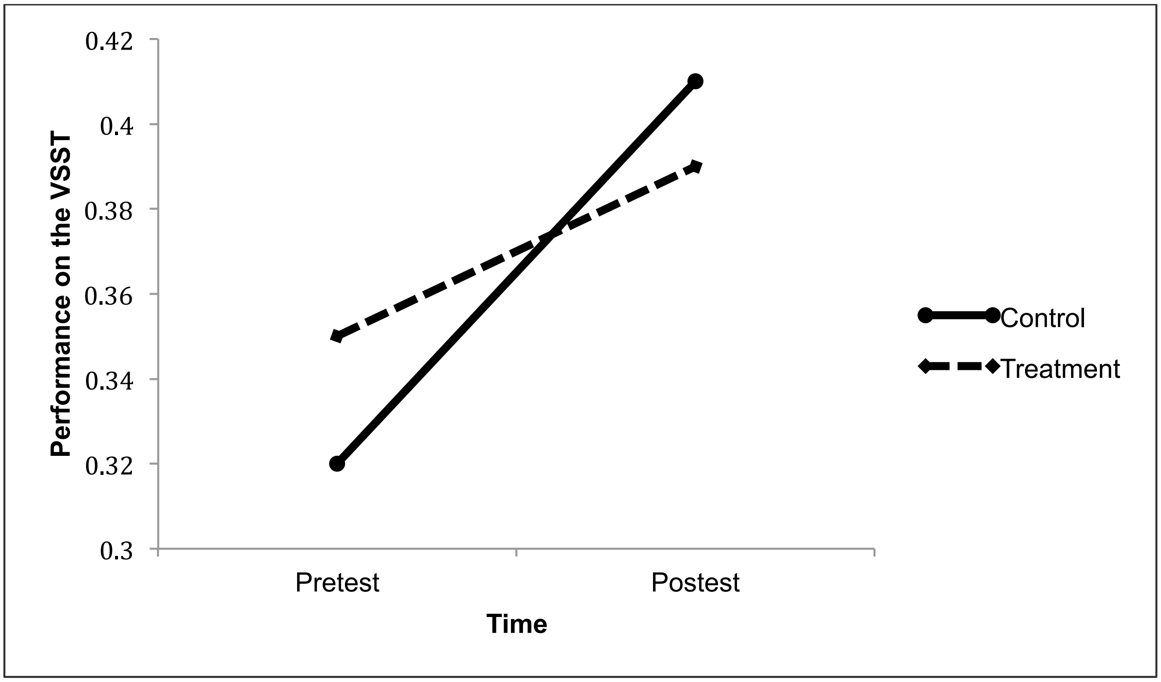


Figure 16. Children's mean score on the VSST in each condition at pre- and post-test.

CREPT. To assess whether there were group or gender differences in children's ability to mentally rotate puzzle pieces, a 2 x 2 mixed ANOVA was conducted with time (pretest vs. posttest) as the repeated measures variable and group (treatment vs. control) and gender (boys vs. girls) as the between subjects variable. For the CREPT, there were no significant main effect ($F(1, 40) = .63, p = .43$) or interaction effects ($F(1, 40) = .12, p = .74$). However, there was a significant main effect of gender, $F(1, 40) = 10.94, p = .002$. This indicates that girls performed better at mentally rotating puzzle pieces than their male counterparts at both pre and post tests. The means for both genders at each time point are presented in Figure 17.

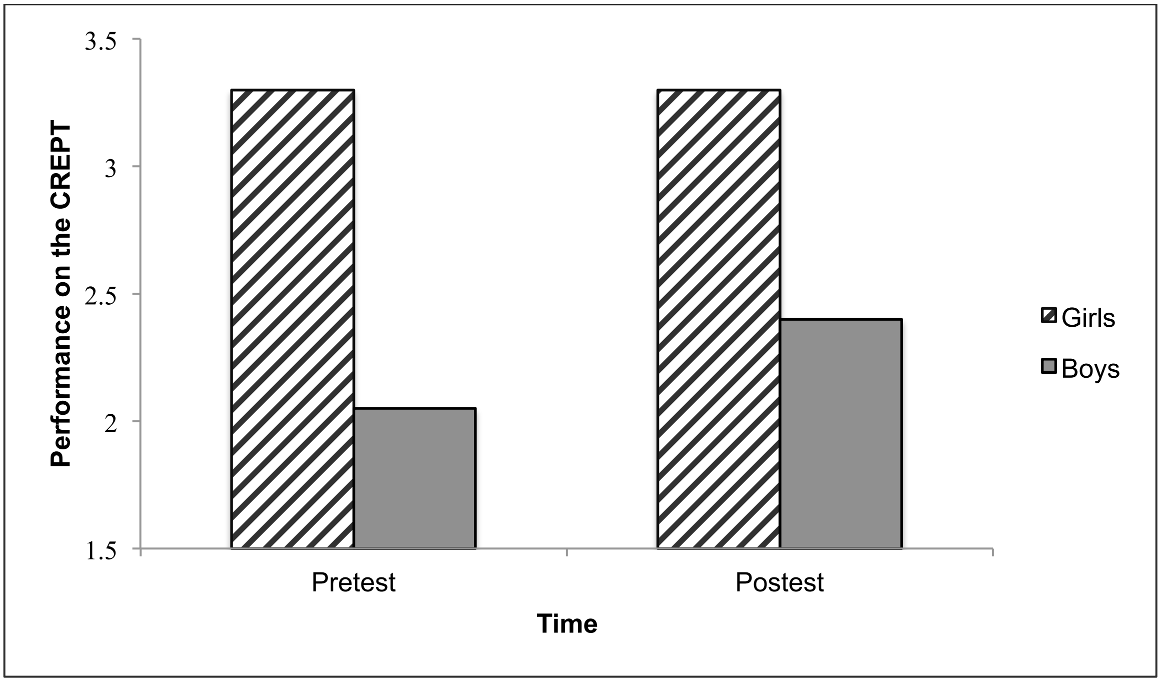


Figure 17. Children's mean score on the CREPT for boys and girls at pre- and post-test.

Chapter V

Discussion

The overall goal of the present study was to develop, implement, and test the effectiveness of a curriculum designed to improve spatial thinking amongst preschool children. Specifically, the study explored the effects of shape-based training on 4-year-old children's ability to disembed and whether the training transferred to improvement in mental rotation skills. Uttal et al., (2013) assert that spatial skills are both malleable and long lasting, as evidenced from an extensive review of the literature. In addition, Uttal and colleagues argue that spatial training is more effective with young children but only a small percentage of studies have focused on this age group. Thus, the present study investigated how two different training programs affected children's performance on a variety of spatial tasks. The curriculum utilized in this study expanded on typical geometry instruction by integrating training on disembedding abilities into lessons focused on teaching children about shape attributes. The treatment condition utilized basic shape activities as a foundation for disembedding while the control condition focused exclusively on basic shape understanding.

Accurate and reliable measures are essential in understanding the developmental progression of spatial skills. There are a limited number of developmentally appropriate measures available to assess preschool children's spatial abilities. In the present study, the children were tested using a standard disembedding task (CEFT) as well as a standard mental rotation task (CMTT) in order to assess improvements in spatial understanding. However, questions remain as to whether these measures are developmentally appropriate for 4-year-olds. The CEFT was originally developed for children between the ages of 5- and 9-years-old but was utilized in the present study because the embedded figures task designed for 3- to

5-year-olds is no longer available. The CMTT has been widely utilized as an appropriate measure of mental rotation but presents abstract figures that may be confusing to young children. Thus, two new measures were created for the purpose of this study. The first new measure involved visually scanning scenic diagrams that allowed children to locate multiple instances and variations of the target shape. The second new measure involved discerning rotated puzzle pieces in a dynamic embedded figures task that also to incorporated mental rotation. A question of interest was whether these new measures had spatial components that overlapped with each other and the CEFT and CMTT as evidenced by their correlations.

A major finding in the present study was that children's scores on the CMTT (standard mental rotation task) were significantly positively correlated with scores on one of the newly developed measures, the Children's Rotated Embedded Puzzle Task (CREPT). This finding suggests that similar mental processing skills were used in solving both the standard measure as well as the newly developed measure. The CMTT required the children to make inferences about abstract figures by attempting to mentally rotate one stimulus to align it with a comparison stimulus. Similarly, the puzzle task required the children to make inferences about a rotated puzzle piece by mentally rotating it to locate the correct placement within a puzzle template.

In addition, performance on the CREPT was positively associated with performance on the other newly developed measure, the VVST. This task required the children to scan a visual scene and locate hidden shapes in a diagram. Both tasks required that children disembed shapes from a configuration of shapes. This correlation also suggests some overlap in mental processing used to perform these tasks. However, the standard embedded figures task, the CEFT, did not correlate with either of the new measures. One possibility is that the new measures are measuring dynamic disembedding skills whereas the CEFT only measures static disembedding skills. Nonetheless, these findings have implications for the design of new measures of mental rotation and disembedding that straddle the intrinsic-static and intrinsic-dynamic dimensions and make use of enjoyable play activities for 4-year-old preschool children.

Findings in this study show that demographic factors were associated with young children's spatial reasoning abilities. Girls scored significantly higher on the CREPT task than boys did, suggesting better dynamic disembedding skills. One potential reason that girls may be better at disembedding is because they spend more time coloring, drawing, and painting than boys. Coates, Lord, and Jakabovics (1975) found that children who participated in more activities such as puzzle play and painting exhibited more advanced disembedding skills. However, on the static disembedding task (CEFT) there were no gender differences. While the literature on spatial reasoning abilities clearly shows that boys have an advantage over girls on mental rotation skills, questions remain about gender differences amongst other components of spatial skills.

There is very little research regarding the association between spatial reasoning skills and children's socioeconomic backgrounds. A novel finding in the present study was that children whose mothers had highly educated backgrounds performed better on the CEFT than did children whose mothers had less educated backgrounds. Specifically, children whose mothers had completed a graduate degree were better able to discern embedded triangles than children whose mothers had completed high school. One potential reason for this SES advantage is that children from higher SES backgrounds are raised in more stimulating environments that afford them access to activities and materials (e.g., books, toys, puzzles) that promote spatial thinking. Along this line of thinking, it makes sense then, that all of the scores on the spatial reasoning tasks were also positively associated with timing of entry into preschool. That is, children who spend more time in preschool have more exposure to activities and materials (e.g., blocks, Legos, puzzles) that contribute to the development of spatial thinking. These findings underscore the benefits of the preschool experience in enhancing spatial reasoning skills, which is particularly critical for children from low SES backgrounds.

The relationship between cognitive abilities and bilingualism has been widely reported in the literature (Barac & Bialystok, 2012; Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008). Specifically, it has been found that bilingual children have an advantage when retaining and processing information that present challenging demands on their executive functions (Morales, Calvo, & Bialystok, 2013). Similarly, the present study found that children from bilingual home environments performed better on the puzzle mental rotation task (CREPT) than children from monolingual Spanish homes. Ben-Zeev (1977) found that bilingual 4- to 8-year-old children presented more advanced processing of information skills than their monolingual counterparts. Specifically, she found that bilingual children were better at perceiving and reorganizing perceptual verbal or symbolic information. Bialystok (1999) also found that bilingual 4- and 5-year-olds showed more advanced selective attention when processing tasks with distracting information (e.g. the Dimensional Change Card Sort Task; Zelazo, 2006). This indicates that bilingual children demonstrate more attentional control than monolingual children when confronted with difficult perceptual information. In the present study, the bilingual children may have exceled on the CREPT because the task required inhibitory control in order to ignore distracting perceptual cues. However, it was also found children from monolingual English home environments demonstrated more advanced disembedding skills on the VSST compared to children from bilingual home environments. Although children from monolingual English environments demonstrated more advanced disembedding abilities, this is likely due to the association between home language environment and education level.

The primary question of interest in this study was whether a shape instruction curriculum that trained children to disembed shapes would improve their spatial reasoning skills as compared to a shape instruction without disembedding training. Children showed improvement on three of the spatial measures but there were no intervention group effects. That is, both the treatment and control group children improved in their ability to recognize shapes and disembed shapes, as measured by the CEFT, and also to locate shapes in a scenic diagram (VSST). These findings suggest that learning about shape properties, raising attention their outlines, viewing shapes in different contexts, and engaging in hands-on activities, enhances children's ability to distinguish these figures from their backgrounds. Additional training on disembedding may be helpful and engaging for children but it may not be necessary to improve children's ability to locate embedded shapes. More information is needed to determine what features of the control group curriculum enhanced the children's disembedding skills. One explanation is that general exploration of shapes is sufficient in improving children's ability to disembed shapes because children gain more familiarity with both prototypical and non-prototypical shapes.

When comparing children's pre- to post-test gains on the VSST, children located an average of 4 more shapes on the post-test than they did on the pre-test. The children were given 30 seconds to find shapes in both the pretest and the posttest. It is important to note that children in the posttest were able to locate more shapes because they became *faster* at locating them. This may be attributed to more effective scanning of the visual scene. This raises questions related to how the curriculum induces changes in basic and attentional processes. More flexible attention capacities (shifting focus between multiple figures) may be a factor underlying the improved performance on the VVST.

It was speculated that having the opportunity to see shapes in different orientations might result in the improvement of mental rotation skills. In the present study, training children to disembed did not transfer to mental rotation skills as evidenced by the lack of improvement on pre- to post-test scores. One possible reason is that improving mental rotation skills requires deliberate practice. Practice on disembedding shapes in dynamic ways simply does not transfer to children's ability to mentally rotate figures. However, another possible reason has to do with the nature of the measure itself. The figures explored in the curriculum were different from those introduced in the test measures. The curriculum provided practice in building specific knowledge of well-known shapes (e.g., circles, triangles, squares, and rectangles) in different skews and orientations. In contrast, the standard mental rotation task as well the CREPT involved processing of figures that the children were not exposed to in the curriculum. The figures in the standard mental rotation task and the CREPT were abstract and did not represent a common figure familiar to the children. Therefore, practice with familiar shapes may transfer only to measures that include highly similar shapes as was the case with the CEFT and VSST.

Had the mental rotation task and the puzzle piece task utilized recognizable triangles and rectangles, or if children were trained to disembed abstract figures as, a different pattern of findings may have emerged.

In the present study, children also completed a task that asked them to locate valid instances of circles, triangles, and squares in a measure designed by Clements et al., (1999) to assess their general shape understanding. Overall, circles were the easiest shape for children to identify, followed by squares, and then triangles. This finding is consistent with studies on children's basic shape knowledge (Clements & Sarama, 2000; Clements & Sarama, 2014). Children in the present study also located more prototypical triangles and rectangles than non-prototypical triangles and rectangles on the visual search task. Perhaps the ways in which children typically learn about shapes, through worksheets and diagrams, do not provide enough hands-on exploration of non-prototypical triangles and squares.

Compared to previous studies, the children in the present study exhibited more difficulties locating embedded figures on the CEFT. This is evident in the average difficulty index of .46. In a previous study, Bowd (1976) reported an average item difficulty of .58 amongst 90 kindergarten through 2nd grade children and Hardy, Elliot, and Burlingame (1984) reported a much higher item difficulty of .74 amongst 240 kindergarten through 4th grade children. These two studies may have reported higher difficulty index scores because the sample included older children. For this age group, it may also be meaningful to consider the valid instances of triangles the children located instead of only giving credit for locating the target triangle. Considering the valid instances of other located triangles provides more information as to the disembedding abilities of 4-year-old children. In addition, the children included in the present study performed similarly to children in a study by Levine et al. (1999) on the CMTT. Levine and colleagues found that 4-year-olds performed significantly above the level of chance, indicating that the task was a reliable means of testing young children's mental rotation skills. In the present study, children performed above the level of chance as well but the average difficulty index was .39. This indicates that the task may have been too difficult for this age group.

Limitations

The present study found that 4-year-old children's ability to disembed shapes improved though participating in training that included hands-on exploration of shapes. Although children exhibited pre- to post-test gains, several limitations to the present study exist. One limitation was the small sample population. Because the sample only included 45 children in the pre-test and 40 children in the post-test, the results may not be representative of the larger population and thus, may not be generalizable. Also, there were also only a small number of test items utilized in each measure. This may have affected the power of the analyses and reduced the ability for each measure to accurately assess children's abilities. For future studies, it is important that the tasks be replicated with a larger sample size and more test items for each task. However, the brevity of each task in the present study allowed for more tasks to be included, which was important in developing and testing the new spatial measures.

Another limitation was the length of the interviews. The interviews lasted an average of 15 minutes. Towards the ends of the interviews, some of the children presented behaviors that indicated they might have been tired such as yawning, looking around the room, or resting their head on the table. Mental fatigue has been shown to effects children's ability to process information and may have negatively impacted children's performance on the later tasks (e.g., the VSST and CMTT). The children were allowed to choose a sticker after each task, which appeared to help motivate them. However, future studies that include more test items may benefit from conducting the interviews over multiple days.

A final limitation of the present study was the lack of a control group in which children were not exposed to any curriculum. This would have allowed for a more in depth understanding of the effects of both the intervention and control group curriculums. It is important for future studies to explore what practice effects exist by including a control group of children that do not participate in any curriculum and are simply pre- and post-tested a week apart.

Conclusion

The present study made contributions to the field of research on children's early spatial abilities by exploring the effect of training on the spatial skill of disembedding. Studies that have examined children's ability to disembed have primarily utilized a singular standard measure that may underestimate children's ability to locate hidden figures. The present study contributes two new spatial measures that can be utilized in future studies to assess children's disembedding and mental rotation abilities. In addition, these new measures may provide more developmentally appropriate tasks for 4-year-old children.

In addition, findings from the present study suggest that children's disembedding skills can be improved through basic shape instruction. Extensive training on disembedding over three lessons may have been more than necessary to improve disembedding skills. Highlighting the outlines of shapes and providing hands-on opportunities to manipulate shapes was sufficient in helping children detect these shapes in complex diagrams. Therefore, enhanced shape instruction has implications not only for shape recognition but also helps develop children's spatial skills.

Because disembedding can be learned through everyday shape activities, activities that encourage mental rotation could be incorporated to produce a more intensive curriculum that not only improves preschool children's ability to disembed, but potentially improves their ability to mentally rotate figures as well. It is essential to develop engaging and appropriate curricula for early childhood classrooms as these experiences contribute to later proficiency in mathematics.

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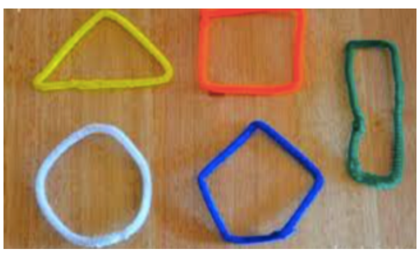
Appendix A

Intervention

Lesson 1

***Activity 1*: Create shapes out of pipe cleaners (5 minutes)**
Good morning everyone! Today we're going to be learning about shapes! What shapes do you know? (Hold up each shape as children name them. Make sure to include square, triangle, circle, rectangle). Now, we're going to try and make those shapes out of these bendy pipe cleaners. You can bend the pipe cleaner to make the shape you want. Let's start with a circle. (Give each child a pipe cleaner and let them attempt on their own. Provide cues if needed). A circle goes all the way around. Now let's try a rectangle. Rectangles have a 2 long sides and 2 short sides. How about a square next? A square has four sides that are all the same length. What's last? That's right, a triangle! Let's see if we can bend a pipe cleaner into the shape of a triangle. It should have three sides and three corners. Great!

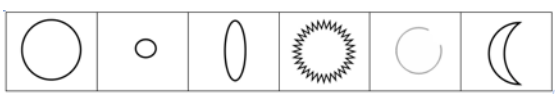


***Activity 2:* Discuss and sort valid and invalid examples of shapes using knowledge of shape properties. (12 minutes)**
Next, we're going to play a game. This is Celia and she needs help choosing shapes for her art project. Can you guys help her? Great! I'm going to hold up a shape, and I want you to tell me what shape it is. Celia needs squares, triangles, rectangles, and circles for her art project. There might be some tricky ones that aren't shapes at all so make sure to look closely. If you think it's a shape, we'll give it to Celia. If not, we'll put it to the side.

Triangles. What shape is this? (Hold up flash card with prototypical triangle) That's right. It's a triangle! Now, what do you see when you look at this triangle? (Encourage children to describe a triangle. Responses may include that it has three sides or three points). That's right, triangles have three sides and three points. Let's give it to Celia! Do you think this one is a triangle also? (hold up skewed triangle) How do you know it's a triangle? That's right, because it has three sides and three vertices or points. Let's give this shape to Celia! What about this very very small shape? (hold up flash card with small triangle) Is it a triangle? How do you know? (Continue through each triangle example). What about this shape? (Hold up triangle shape with rounded sides) Do you see it has bent sides? That means it isn't a triangle. Remember, triangles have to have straight sides. So even if a triangle is really big or very skinny or turned on it's side, its still a triangle if it has three sides and three corners. But if the shape has bent sides or has a part missing, it isn't a triangle.

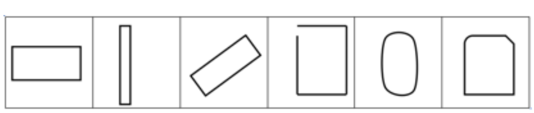
Triangles included on the flash cards.

Circles. "What shape is this? That's right, this is a circle. How do you know it's a circle? (Encourage children to describe a circle. Responses may include that it is round and has no sides). That's right, circles are perfectly round and have no sides. Let's give it to Celia for her art project! Do you think this one is a circle also? (Hold up small circle) How do you know it's a circle? That's right, because it is perfectly round and has no sides. What about this shape? It looks like a circle that's been stretched out. Is it a circle? No, its not a circle because isn't perfectly round so we won't give this one to Celia. What about this one? (Hold up circle with open side) This one is not a circle because it doesn't go all the way around. It's missing a piece! (Continue through each circle example).



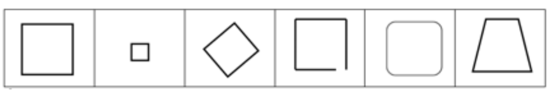
Circles included on the flash cards.

Rectangles. "What shape is this? That's right, this is a rectangle. How do you know it's a rectangle? (Encourage children to describe a rectangle. Responses may include that has four sides, four corners, 2 long sides and 2 short sides) That's right, rectangles have four straight sides and four corners. Do you think this one is a rectangle also? (Point to tall skinny rectangle) How do you know it's a rectangle? That's right, because it has four sides and four corners! It also has two long sides and two short sides. What about this shape? Is it a rectangle? How do you know? That's right. It isn't a rectangle because it has curved/round corners so we won't give this one to Celia (Continue through each rectangle example). Remember, even if a rectangle is really big or really small, or turned on its side, its still a rectangle if it has four sides, four corners, and 2 long sides and 2 short sides."



Rectangles included on the flash cards.

Squares. "What shape is this? That's right, this is a square. How do you know it's a square? (Encourage children to describe a square. Responses may include that has four straight sides and four corners). That's right, squares have four straight sides and four corners. But wait, don't rectangles have four straight sides and four corners? How do we know these are squares and not rectangles? That's right, rectangles have 2 long sides and 2 short sides and squares sides are all the same length. Do you think this one is a square also? (Point to large square) How do you know it's a square? That's right, because it has four sides and four corners. Let's give this one to Celia! What about this one? Is it a square? How do you know? (Hold up square with missing piece) It isn't a square because one of the sides is broken. What about this one? (Hold up square rotated at an angle) It looks like a diamond but watch what happens when I turn it. It's a square! So remember, if we turn our heads we can tell if it is a square. (Continue through each square example). So even if a square is really big or really small, or turned on its side, its still a square if it has four sides the same length and four corners."



Squares included on the flash cards.

Activity 2: Create a sailboat using pre-cut basic shapes. (8 minutes)
Okay, next we're going to use the shapes that we chose for Celia to make a boat! Who knows what a sailboat is? Sailboats use the wind to move around in the ocean. I have some pictures of different sailboats. Do you see that some parts of the sailboat looks like shapes? Let's see if we can make our own sailboats using different shapes.

(Hand each child a blue piece of construction paper) This paper is going to be our ocean. (Put shape cutouts on the table) We're going to use these different shapes to make a boat. Lets start with the bottom of the boat. What shape could we use as the base? (Suggest square or rectangle if no response). Let's glue it down! What about the sail? What shapes could we use to make a sail? Let's try this really skinny rectangle and then put a triangle on it. You can use the circles to make windows too! You see, we can put shapes together to make different pictures.

Lesson 2

Activity 1: **Sorting valid and invalid examples of shapes using knowledge of shape properties. (3 minutes)**

Good morning everyone! Can you guess what we'll be doing today? That's right, we're going to be exploring with shapes again! First, we're going to play a quick game. In this game, we're going to look at pictures and decide if they are a shape or not. Remember, if it's a shape, we give it to Celia. When I show the first card, I want you to tell me what shape it is or if it isn't a shape at all. Okay?

(Use shape images from lesson one, activity 2. For each shape, ask the children what shape it is. Ask for explanations if they don't think it's a shape.)
Example: "Is this a shape? That's right, it's a triangle. How do you know? Because it has three sides and three corners! Is this a shape? No? Why not? That's right, because the sides of the square are bent!

Activity 2: Dip 3D geometric solids onto stamp pads and stamp the sides onto a piece of paper. Children will be encouraged to rotate, flip, and physically explore the shapes to see different sides. (12 minutes)

Now, we're going to talk about a different type of shapes. Who likes to build with blocks? Great! Those are the shapes we're going to be talking about; shapes that we can build with! First, I am going to give everyone a big piece of paper. We're going to use our special blocks to find hidden shapes. (Hand out white construction paper)

Pyramid. "Let's start with this one! Can you guess what it's called? It is a pyramid. What do you see when you look at the pyramid? Children may respond with square base, point on top, or four triangle faces. Go over each.) Let's try stamping with it. You can dip one side into the ink and then stamp it on your paper. Do you see the triangle you made from stamping the side? (Encourage children to rotate pyramid) Let's stamp the bottom of the pyramid. Do you see what shape is on the bottom? A square is on the base! Wow! So shapes can come together to make other shapes! A pyramid has a lot of different shapes.

Cube. Let's do this shape next. Do you know what this shape is called? It looks like a square but we call this one a cube because it's made of lots of squares. What do you see when you look at the cube? That's right, there are a lot of squares that make up the cube. Let's try stamping with it!

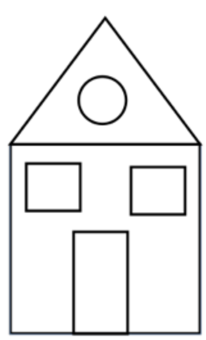
Rectangular prism. This one has a long name. It's called a rectangular prism. Can you say rectangular prism? Good! What do you see when you look at the rectangular prism? That's right, there are a lot of rectangles that make up the rectangular prism. Let's see if we can stamp them! We can make big and small rectangles with the rectangular prism. Who remembers what a rectangle is? A rectangle has two long sides and two short sides. How many pointy corners? That’s right, four pointy corners. All of these rectangles come together to make the rectangular prism. Remember that shapes can come together to make other shapes!

Triangular prism. This one also has a long name. Can anyone guess? It is called a triangular prism. What do you see? That’s right, there are triangles! Let’s stamp them on our paper! What else do you see? Let’s turn it to find different shapes. That’s right, there are also rectangles. So a triangular prism is made up of rectangles and triangles.

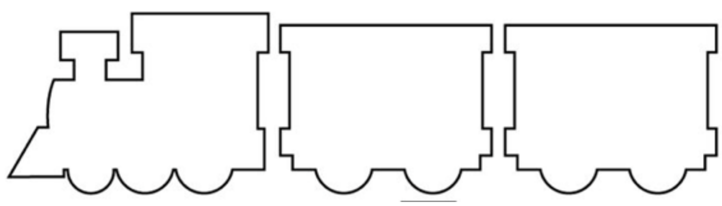
Cylinder. This is our last shape. Do you know what this one is called? It’s called a cylinder. Can you say cylinder? Good! What do you see when you look at the cylinder? That’s right, there’s a circle on the bottom and top. Let’s stamp it! What else do you see? Do you see that it has a big curve that wraps all the way around? Let’s try and stamp it to see what shape it makes. Wow! It makes a rectangle when you roll it. So two circles and a wrapped around rectangle make a cylinder.

Activity 3: Shapes are embedded in images. Fill in the outline of a train with pre-cut basic shapes. (10 minutes)

Do you remember that some shapes can have other shapes in them and if we look really closely we can find hidden shapes? Who remembers our sailboats from yesterday? What shapes did we use to make our sailboats? That’s right, we used squares, triangles, and rectangles. (Hold up picture of house) Let’s look at this house. What shapes do you see? I see a window that is a square and a triangle roof. What else? That’s right! The door is a rectangle. Remember, if we look really closely we can find all kinds of hidden shapes.



Now, we're going to hide shape in a picture of a train! Let's see which shapes fit where. (Children fill in the outline of a train with simple shapes. Provide pre-cut shapes that children can use. Include different sizes and skews of triangles, circles, rectangles, and squares. Give children the shape cutouts and allow them to experiment fitting different shapes into the outline of the train. Encourage the children to move the shapes around and rotate them.)
I like the way you're using that circle as a wheel! Wow, I see you've hidden a rectangle in the train!

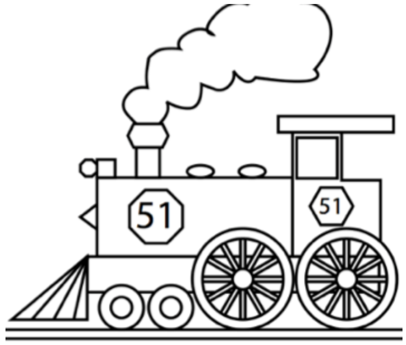


Lesson 3

Activity 1: Visual Search Task: As a group, children locate as many shapes possible in drawing of a train. Children's attention will be drawn to the orientation, skews, and sizes of the shapes. (5 minutes)
Where can you find shapes? Look around the room, do you see any shapes? (wait for children to respond) Yes, that is a _____. Do you see that the ______ is part of the clock/chair/toy/etc.? Allow each child to locate shape in the classroom.

Sometimes, we can find shapes hidden in other shapes. (Use one of the example items children gave) Remember the clock that Sara said was a circle? We can see another smaller circle inside of the clock if we look closely.

Lets look at this train. We can find a lot of shapes hidden in other shapes. What shapes do you see?
(Bring children's attention to the different shapes that make up the train. Allow each child to locate a shape. Go over many different shapes, bringing children's attention to the size, skew, and orientation)



Activity 2: Look at familiar objects and locate embedded shapes. (10 minutes)
Now that we know that we can find shapes all around us, we are going to play an "I Spy" game. Let's see if we can find hidden shapes in some of the toys that I brought. First, I want you to tell me what shapes you see in this fire truck. That's right, there are circles in the tires! And there are rectangles in the ladder! (Allow children to explore the fire truck and identify as many shapes as they can find) Remember, we can turn the fire truck and look at it in different ways to find more hidden shapes. Now, let's look at this house. I am going to say a shape and I want to see if you can find it. I spy a triangle. Who can find a triangle? That's right, there is a triangle on the roof. I spy a square. Can you find a square? That's right, there's a square on the window! What shapes can you find in the house? (Allow children to play with toys after discussing some of the hidden shapes. While children play with toys, bring their attention to shapes that are difficult to find)

Activity 3: Color Code Game – Use transparent overlays to create complex figures consisting of embedded shapes. (10 minutes)
Okay, we're going to play one more game. In this game, we are going to have to act like detectives. Who knows what a detective is? That's right, a detective has to look really hard to find hidden clues. Can you help me find hidden shapes? Great!

(Go through 5 shapes items. Draw children's attention to the shapes they see. Once they discover all of the hidden shapes, remove the transparent overlays to demonstrate how the complex figure becomes simplified. After going through 2 to 3 examples, allow children to use the transparent overlays to create their own shapes)

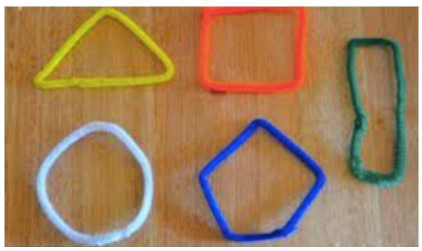
Example: “What shapes do you see? Good! You see a square in the middle. What other shapes do you see? Look really close. That’s right, there are triangles all around it! Now, if we take away the top square, let’s see what shape is underneath. Remember, shapes can be put together to create other hidden shapes.”

Appendix B

Control

Lesson 1

***Activity 1*: Create shapes out of pipe cleaners (5 minutes)**
Good morning everyone! Today we're going to be learning about shapes! What shapes do you know? (Hold up each shape as children name them, square, triangle, circle, rectangle). We can use these bendy pipe cleaners to make shapes. (Place pipe cleaners on table. Do not provide further guidance, allow children to free play with the pipe cleaners.)

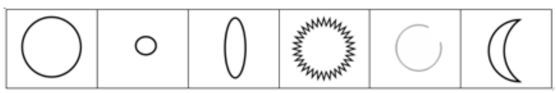


Activity 2: Sorting valid and invalid examples of shapes using knowledge of shape properties. (12 minutes)
Next, we're going to play a game. This is Celia and she needs help choosing shapes for her art project. Can you guys help her? Great! I'm going to hold up a shape, and I want you to tell me what shape it is. Celia needs squares, triangles, rectangles, and circles for her art project. There might be some tricky ones that aren't shapes at all so make sure to look closely. If you think it's a shape, we'll give it to Celia. If not, we'll put it to the side.

Triangles. What shape is this? (Hold up flash card with prototypical triangle) That's right. It's a triangle! Now, what do you see when you look at this triangle? (Encourage children to describe a triangle. Responses may include that it has three sides or three points). That's right, triangles have three sides and three points. Let's give it to Celia! Do you think this one is a triangle also? (hold up skewed triangle) How do you know it's a triangle? That's right, because it has three sides and three vertices or points. Let's give this shape to Celia! What about this very very small shape? (hold up flash card with small triangle) Is it a triangle? How do you know? (Continue through each triangle example). What about this shape? (Hold up triangle shape with rounded sides) Do you see it has bent sides? That means it isn't a triangle. Remember, triangles have to have straight sides. So even if a triangle is really big or very skinny or turned on it's side, its still a triangle if it has three sides and three corners. But if the shape has bent sides or has a part missing, it isn't a triangle.

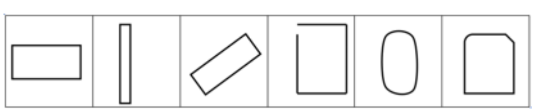
Triangles included on the flash cards.

Circles. “What shape is this? That’s right, this is a circle. How do you know it’s a circle? (Encourage children to describe a circle. Responses may include that it is round and has no sides). That’s right, circles are perfectly round and have no sides. Let’s give it to Celia for her art project! Do you think this one is a circle also? (Hold up small circle) How do you know it’s a circle? That’s right, because it is perfectly round and has no sides. What about this shape? It looks like a circle that’s been stretched out. Is it a circle? No, its not a circle because isn’t perfectly round so we won’t give this one to Celia. What about this one? (Hold up circle with open side) This one is not a circle because it doesn’t go all the way around. It’s missing a piece! (Continue through each circle example).



Circles included on the flash cards.

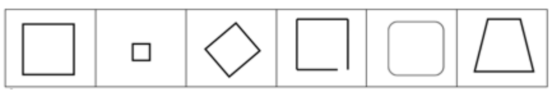
Rectangles. “What shape is this? That’s right, this is a rectangle. How do you know it’s a rectangle? (Encourage children to describe a rectangle. Responses may include that has four sides, four corners, 2 long sides and 2 short sides) That’s right, rectangles have four straight sides and four corners. Do you think this one is a rectangle also? (Point to tall skinny rectangle) How do you know it’s a rectangle? That’s right, because it has four sides and four corners! It also has two long sides and two short sides. What about this shape? Is it a rectangle? How do you know? That’s right. It isn’t a rectangle because it has curved/round corners so we won’t give this one to Celia (Continue through each rectangle example). Remember, even if a rectangle is really big or really small, or turned on its side, its still a rectangle if it has four sides, four corners, and 2 long sides and 2 short sides.”



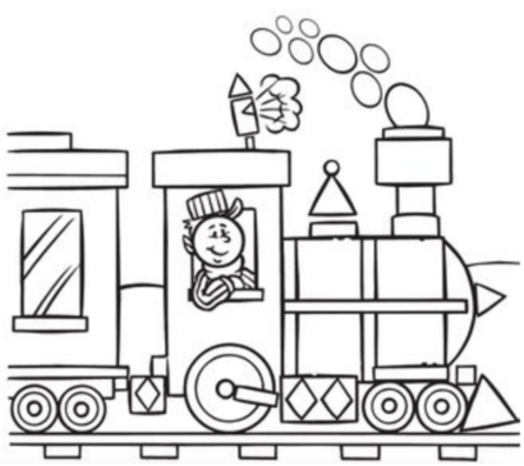
Rectangles included on the flash cards.

Squares. “What shape is this? That’s right, this is a square. How do you know it’s a square? (Encourage children to describe a square. Responses may include that has four straight sides and four corners). That’s right, squares have four straight sides and four corners. But wait, don’t rectangles have four straight sides and four corners?

How do we know these are squares and not rectangles? That's right, rectangles have 2 long sides and 2 short sides and squares sides are all the same length. Do you think this one is a square also? (Point to large square) How do you know it's a square? That's right, because it has four sides and four corners. Let's give this one to Celia! What about this one? Is it a square? How do you know? (Hold up square with missing piece) It isn't a square because one of the sides is broken. What about this one? (Hold up square rotated at an angle) It looks like a diamond but watch what happens when I turn it. It's a square! So remember, if we turn our heads we can tell if it is a square. (Continue through each square example). So even if a square is really big or really small, or turned on its side, its still a square if it has four sides the same length and four corners."


Squares included on the flash cards.

Activity 2**: Color shapes on worksheet. (8 minutes)**
Okay, next we're going to color in this train. (Hand out worksheet to each child and place crayons on the table. Allow children to color without prompting them about shapes)



Lesson 2

***Activity 1:* Sorting valid and invalid examples of shapes using knowledge of shape properties. (3 minutes)**

Good morning everyone! Can you guess what we'll be doing today? That's right, we're going to be exploring with shapes again! First, we're going to play a quick game. In this game, we're going to look at pictures and decide if they are a shape or not. Remember, if it's a shape, we give it to Celia. When I show the first card, I want you to tell me what shape it is or if it isn't a shape at all. Okay?

(Use shape images from lesson one, activity 2. For each shape, ask the children what shape it is. Ask for explanations if they don't think it's a shape.)
Example: "Is this a shape? That's right, it's a triangle. How do you know? Because it has three sides and three corners! Is this a shape? No? Why not? That's right, because the sides of the square are bent!

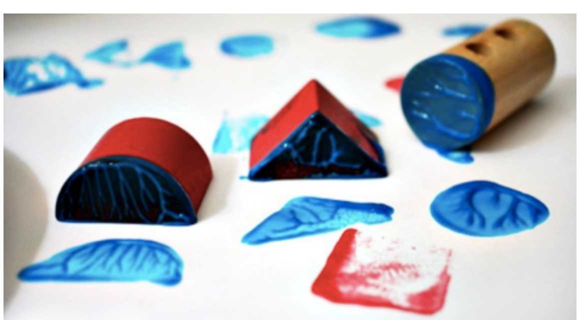
Activity 2: Building with blocks to gain deeper understanding of 3D solids (7 minutes)

Who likes to build with blocks? Good! Me too! I have a bag full of blocks for us to build with. Let's see what we can build!

(The goal of this activity is to provide children with the opportunity to build and explore with blocks. During the 7 minutes, the teacher should engage the children in discussions about what they are building without purposefully drawing the children's attention to the different shapes)

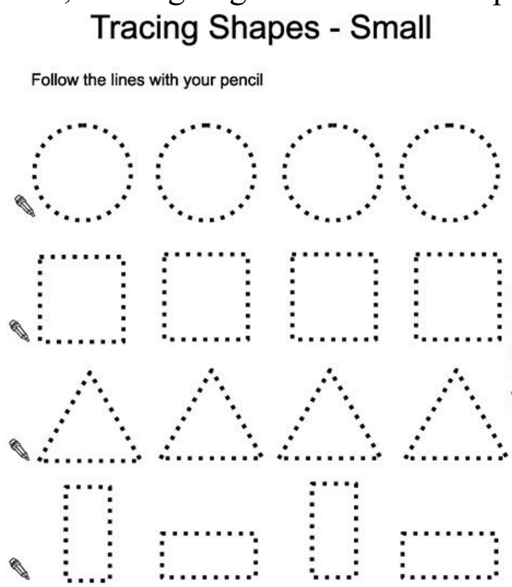
Activity 3: Dip 3D geometric solids onto stamp pads and stamp the sides onto a piece of paper. (15 minutes)

Now, we're going to be using these shapes to stamp with.
(Pass out white construction paper to each child. Put 3D shapes on table; encourage free exploration of the shapes and stamping.)



Lesson 3

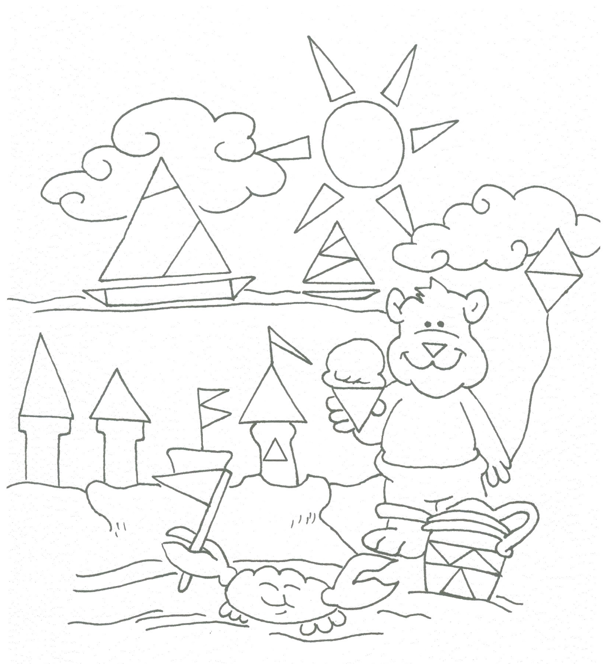
Activity 1: Shape Tracing Worksheet
Next, we're going to trace these shapes. (Hand out a marker to each cild)



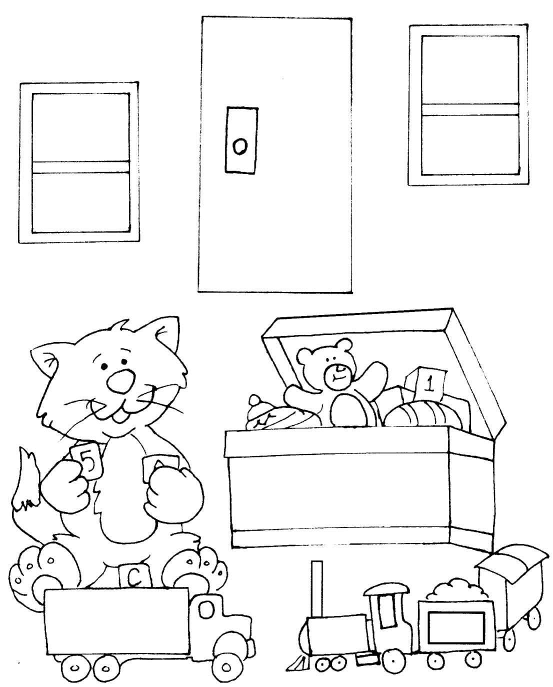
Activity 2: Free play with tanagrams. (10 minutes)
Now, we're going to be playing with these shapes. You can make your own picture or build with them. (Free play with tanagrams)

Appendix C

Triangle Visual Search Task



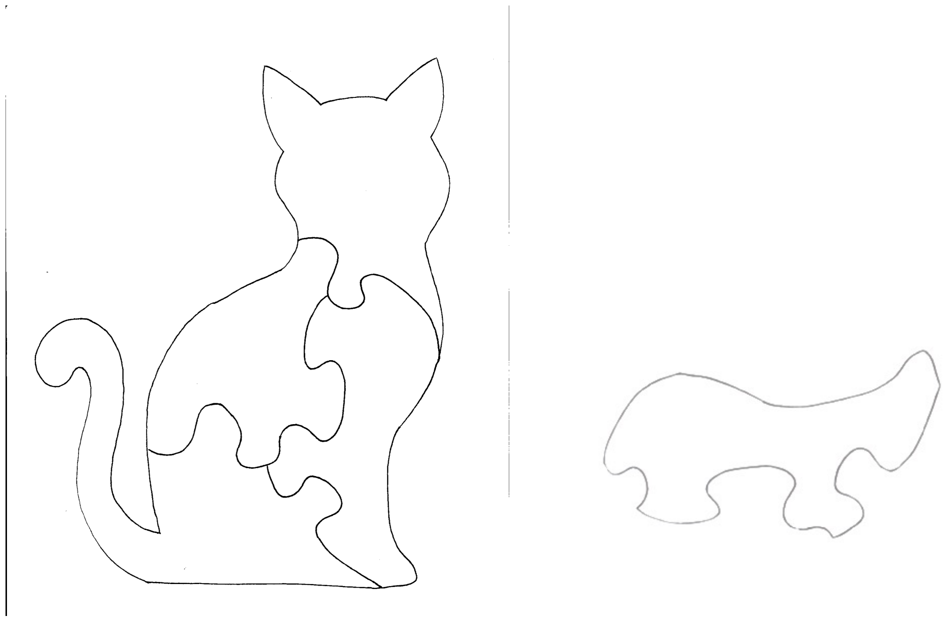
Rectangle Visual Search Task



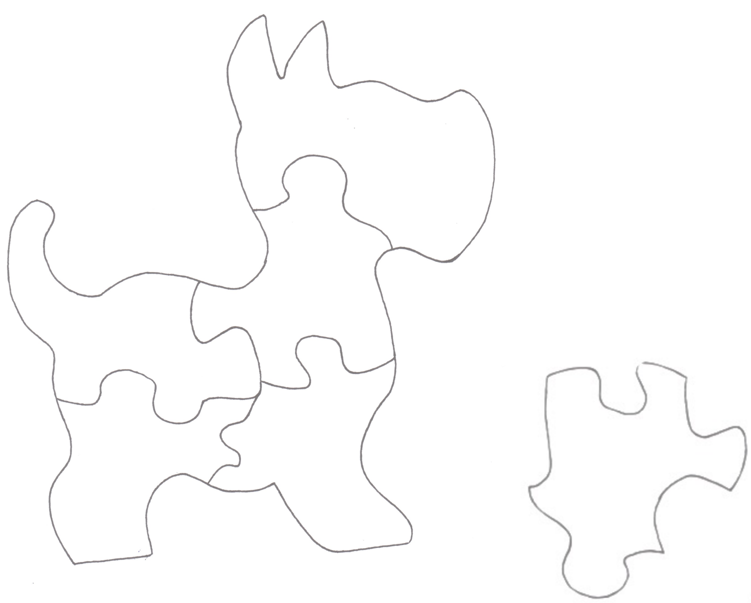
Appendix D

Children's Rotated Embedded Puzzle Task

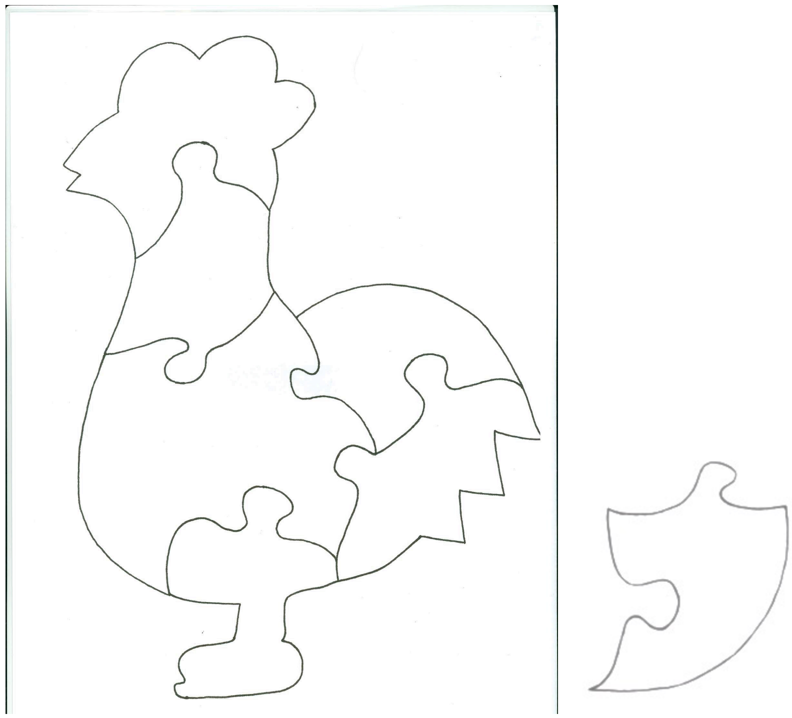
Item 1



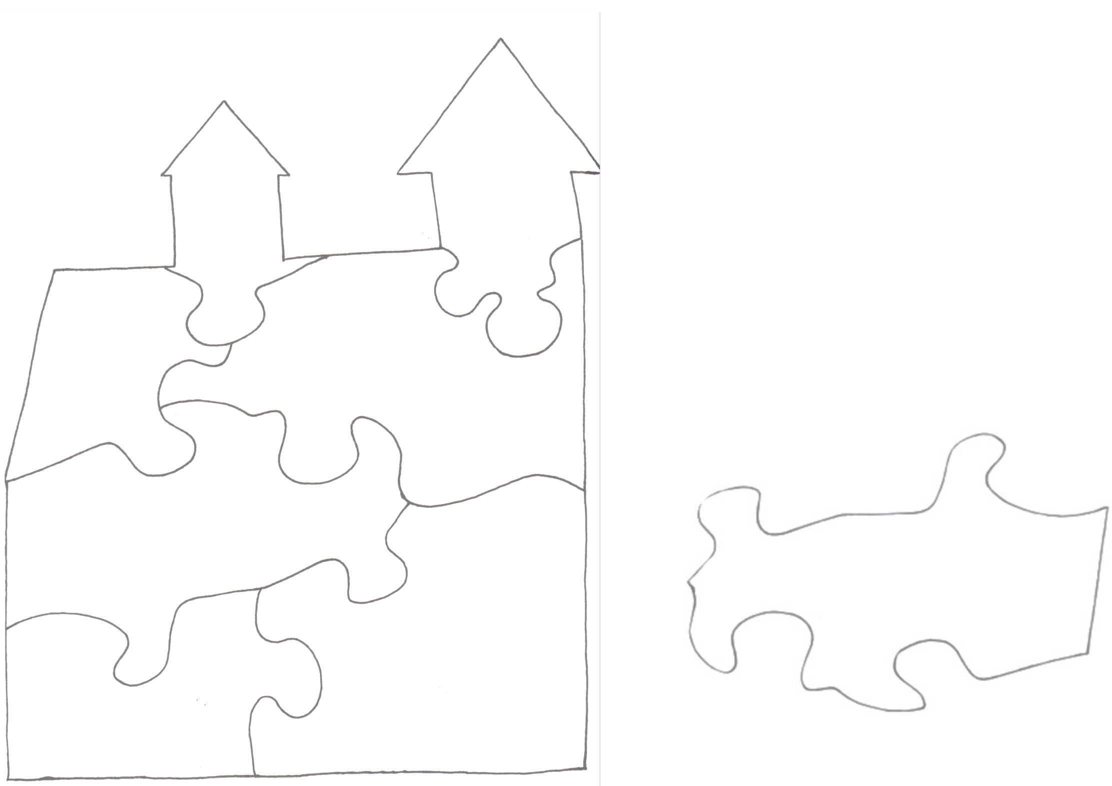
Item 2



Item 3



Item 4



Item 5